The Journal of The New Alchemists

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The Journal of THE NEW ALCHEMISTS · 6 ·

Who Are the New Alchemists?

". . . a small band who work together, bound by a vision of a sustainable future —a kind of New Age Tool and Die Company that can help to create the software or biotechnic technology to realize that vision."

Now celebrating its tenth year, the New Alchemy Institute is a small international organization dedicated to research and education on behalf of humanity and the planet. "Our major task," they say, "is the development of ecologically derived forms of energy, agriculture, aquaculture, housing, and landscapes that will encourage a repopulation and revitalization of the countryside. The Institute has projects in several countries in the hope that our research and experience can be used by large numbers of people in diverse regions of the world."

In this first trade-book edition of their annual JOURNAL, the New Alchemists provide an overview of how their Institute came about, the people who have become actively involved or contributed to its development, the early experiments and their failure or success, their hopes for the future—the future of the Institute and of the world.

How Did They Get Started?

The Organization began when a few concerned people, disheartened by evidence on all sides of an endangered ecosystem, began to ask whether it is, in fact, possible to sustain human populations in ecologically viable ways rather than with the capital-intensive, exploitative, wasteful, and polluting methods presently employed. And if so, how? Increasingly, it appears that it is indeed possible.

In 1975 the New Alchemists teamed up with solar architects David Bergmark and Ole Hammarlund to build the prototype of the bioshelters that were christened "Arks" . . . family-sized solar-heated greenhouses with aquaculture tanks. In 1976 two arks were built; one

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on Prince Edward Island with funds from the Canadian government, and one on Cape Cod. The Cape Cod Ark has weathered every winter since without auxiliary heat and has produced satisfying yields of food and seedlings. Yields from both gardens and solar-algae ponds were exciting. Earlier issues of the JOURNAL recount the simultaneous evolution of the New Alchemy Center in Costa Rica, and are worth tracking down.

What Are Those People Doing Out There?

In THE JOURNAL OF THE NEW ALCHEMISTS No. 6, experts who have been working at the Arks report on their research, experiments, and conclusions to date. Under the subject of *Energy*, you'll find a primer on a water-pumping windmill, and reports on an integrated wind-powered system to pump, store, and deliver heat and cold. Under *Land and Its Use* you'll read of further experiments on the effects of mulches on crop yields and soil conditions; about tree crops that create the foundation of a permanent agriculture; reports on New Alchemy tree crop research. Under *Aquaculture* you'll learn where all the fishes have gone; about cage culture as explored by Bill McLarney and Jeffrey Parkin; what's new and hopeful about solar aquaculture; a summary of fish culture techniques in solar-algae ponds and the energetics involved.

The staff of New Alchemy and Solsearch Architects detail their experiences of the first three years aboard the Cape Cod Ark, and an exploratory section presents a biological perspective of sensitive societies, the economics of renewable-resource-based technologies, and some personal reflections of some of the New Alchemists.

Looking back on ten years of effort, Nancy Jack Todd concludes, "the results of our research, especially when compared in scale with the funding and personnel that go into more orthodox paths, indicate strongly that a sustainable future based on an earth-kindly ethic and nonviolent technology is within the limits of the possible, indeed, well within our grasp."

When you've read THE JOURNAL OF THE NEW ALCHEMISTS No. 6, you'll know why.

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The Journal of THE NEW ALCHEMISTS—6

The New Alchemy Institute

The Stephen Greene Press, Brattleboro, Vermont

THE NEW ALCHEMY INSTITUTE is a small, international organization dedicated to research and education on behalf of humanity and the planet. We seek solutions that can be adopted by individuals or small groups who are trying to create a greener, kinder world. Our major task is the development of ecologically derived forms of energy, agriculture, aquaculture, housing, and landscapes that will encourage a repopulation and revitalization of the countryside. The Institute has centers in several countries in the hope that our research and experience can be used by large numbers of people in diverse regions of the world.

The Institute is nonprofit and tax-exempt and derives its support from private contributions and research grants. Grants for the scientific research are usually available, but adequate funding for general support remains uncertain. The success of the Institute will depend upon our ability to address ourselves to the genuine needs of people working on behalf of themselves and the earth, and on the realization by our friends that financial support of our research is essential if the task ahead is to be realized.

The New Alchemy Institute has an Associate Membership ($25.00 per annum, tax-deductible) which is available to those interested in helping support our work. Upon joining, Associates receive the current annual *Journal of the New Alchemists.* Newsletters and other special interest mailings sent throughout the year keep Associates further informed of the work in progress. Over the years, the support of our Associates has been critical to the continuance of the Institute and its work.

Associate Membership
for Individuals and Families — $25 *per annum*

Contributions of larger amounts are very much needed, and if you can afford more that would be beautiful.

Sustaining Membership — $100 *per annum*
Patrons of the Institute — $1000 *or greater*

Friends wishing to have their membership payment qualify as a deductible contribution under the tax regulations of Canada should make Canadian dollar payments payable to the New Alchemy Institute (P.E.I.) Inc. All other membership contributions should be made payable to New Alchemy Institute. Because of the costs involved with collection charges and currency exchange, we ask that all payments to the New Alchemy Institute, except for Canadian membership, be in the form of United States dollar instruments, preferably International Money Orders.

We invite you to join us as members of the New Alchemy Institute. A company of individuals addressing themselves to the future can, perhaps, make a difference during these years when there is waning reason to have hope in the continuance of human history.

THE NEW ALCHEMY INSTITUTE
P.O. Box 47
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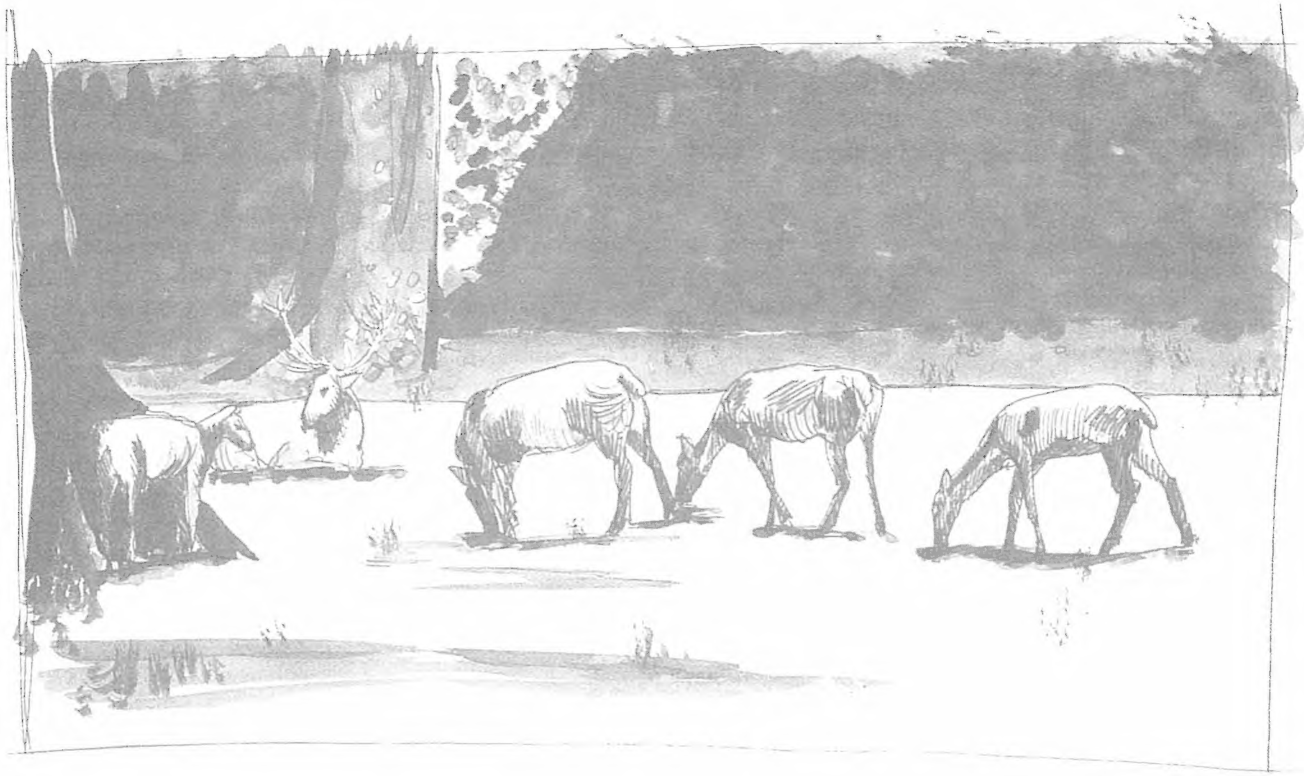
Editor	*NANCY JACK TODD*
Technical Editor	*ROBERT ANGEVINE*
Membership Chair	*CHRISTINA C. RAWLEY*
Cover and Divider Artist	*JEFFREY PARKIN*
Drawings	*JORGE ENRIQUE BUENO* *CALLEY O'NEIL* *NEW ALCHEMISTS* *SOLSEARCH ARCHITECTS*
Photography	*HILDE MAINGAY* *RON ZWEIG* *JOHN TODD*
Proofing	*ROBERT ANGEVINE*
Typing	*CYNTHIA KNAPP* *JANE RUNGE*

Contents



On the island of Bali in Indonesia, in July of 1977, the Pacific Science Congress convened a conference on the subject of appropriate technology. As part of the dialectic inevitable to such occasions, both official addresses and private conversations were involved as much in debate over the failure of the Western, industrial, technological paradigm as they were with the appropriateness of alternative approaches. One day at lunch the talk turned to speculation as to why we, as the apparently rational products of modern civilization, had such difficulty in moderating or envisioning limits to our ever more powerful technologies, both peaceful and military. Why do we seem bent on consuming and expanding far beyond need, reason, efficiency or even survival? It was at about such a turn in the collective train of thought that Margaret Mead, who was on the American delegation, fired one of her unforgettable broadsides. "Well, you know," she pointed out, as though all of us did, "there's no 'no' in the unconscious."

Like so much that is obvious, it was so insightfully simple, self-evident even. But I think that many of us, although we accept the idea theoretically, have failed to incorporate it into our understanding of human behavior. Fundamentally, we are still insatiably curious, exploratory creatures. This is borne out by the most ordinary observation. One need only witness the outrage of a two-year-old at any limitations placed on her or his compulsive investigations of the world. An outburst of fury is most frequently followed by an adamant "no" hurled as a defiant tool of self-definition against the adult's world. Perhaps as a culture we are still caught in the dilemma of the terrible two. Our earlier concept of manifest destiny and its present extension in technological development, the arms race, or the recent, almost religious enthusiasm for space colonies certainly bear out Dr. Mead's statement. As so many of our myths from Pandora to Eve have taught, in the depths of our being, there is no 'no'. Limits must be imposed. They are learned.

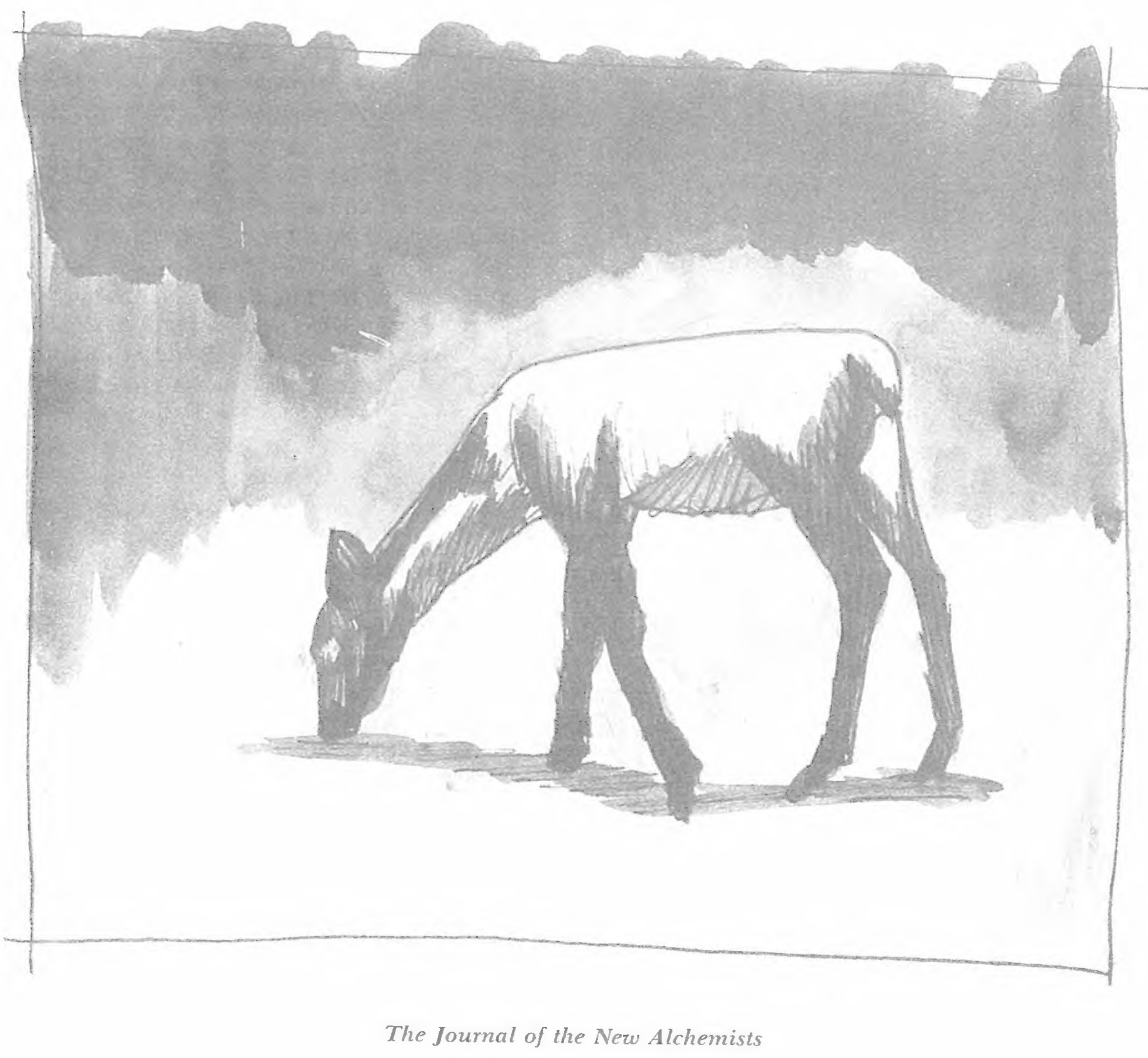
Perhaps it is not so bad to be, at heart, an affirmative rather than a negative creature, but the agonizing paradox in which we currently find ourselves lies in the probability that, without integrating a sense of limitation into our understanding and into our behavior, it is unlikely that we shall survive. It may be that it is the extremity of the exigency of our dark predicament that will ignite our conciousness, and, sparking some long inactive synapse, foster a realization of mutual destiny with each other and with the earth, and that this, in turn, will serve to moderate our behavior. There is, in the nature of all of us, a side that is concerned with nurturing, conserving and preserving. It is most often described as the immanental, feminine principle defined in contrast to the outreaching, transcendent, masculine principle. The yin yang is the best visual image of creative tension and balance between two

such opposing realities. It is this equilibrium between endless questing and what William Irwin Thompson has called the "interiorization of consciousness" that is to be hoped for on an individual and on a planetary level synergistically.

There is an old adage that one can't change human nature; but perhaps it's not an absolute, although for a century that began with the hubris of the Titanic, our slowness to seize on its implications seems to corroborate it. Yet, at this juncture, wherever one lives and whatever one's culture, it is becoming increasingly impossible to continue, ostrich-like, to pursue the path of expanding industrialism and development, for the evidence of its barrenness and folly is everywhere. If before the near melt-down at Three Mile Island, the dangers of nuclear power were understood by comparatively few, the shock waves resulting from the accident there may well create a turning point for the nuclear industry. And if we are forced to abandon nuclear power, we abandon with it forever the idea of a society structured on cheap, accessible fuel even though, for the interim, that is the one in which we go on living.

Although the analogy of nuclear energy is perhaps the most obvious one because it is so endlessly unforgiving, the countless other incidents of pollution of the soil, air and waters have become sufficiently widespread as to be no longer an abstraction, but a discernible reality in the lives of a great many people. For urban dwellers this is a truism, but rural and even tribal peoples are suffering as well. People whose area has been strip-mined or used as a deposit for industrial wastes or those living near plants like Four Corners have hardly less dramatic experiences than the inhabitants of Nevada who lived near the atomic testing sites of the fifties. Native Americans who have fled our world and chosen to return to their ancestral ways cannot do so because so much of the wild life that they relied on to sustain them is gone. Abroad, representatives of developing countries are beginning to look accusingly at us because our missions of development have most often served to exacerbate their problems. The masses of uprooted people crowding into cities can never hope to drive cars and yet must continue to breathe the worsening smog.

Yet it may be that our greatest hope now lies in this



crescendo of evidence of our failure. Cyberneticists talk of feedback, of information that has a flow and is circular, whereas we have been accustomed to think in a linear mode of cause and effect. Unquestionably a model consisting of multiple feedback loops is a more accurate and useful way of trying to understand the world. We receive daily an extraordinary range of information through the experience of our own senses as well as that which most of us receive through the media. Such feedback may be the best means we have for awakening large numbers of people. If the ability to say no to a culture predicated on carcinogenic growth does not lie innate within us, surely, like two-year-olds, we are capable of eventually learning and incorporating it into our actions. If we are exploring creatures, it is because that kind of behavior, for millennia, had survival value. It was most often successful. Now the news begins to come in irrefutably from every side that this is no longer so. This is what we shall have to learn and to internalize.

Just a few months before her death, I heard Dr. Mead speak again. She was addressing thousands of people and the subject of her talk was the future. As ever, she brought to it her own fierce commitment to the hope of continuation of the human family. One story she told was based on Fraser Darling's studies of the Red Deer in Scotland. According to his observations, in times of stress, like drought or famine, it was the habit of the herd to turn to its oldest females because in them lay the composite memory and wisdom of the herd. Usually they could remember back to a time of comparable need and lead the herd to a watering hole or an outcropping of lichen that would otherwise not have been known. And so the herd would survive.

With Dr. Mead's death we have lost one of the wisest among us. Stephanie Mills once said that she was one of the angels who walked among us for a while. Yet still we have a few equivalents of the oldest of the Red Deer that could guide us through the cultural readjustment that the post-industrial period is likely to bring. They may be as widespread as the cultures of indigenous peoples who still live in mutual reciprocity with their environment, in the reawakening religious respect for all sentient beings, or in the Gaia hypothesis that has emerged from the most advanced biological research which envisions the earth and biosphere as a giant living pulsating cell. They may lie in the mind in the waters of the whales and the dolphins if we could learn to understand them.

From our own work at New Alchemy and from that of many other like-minded groups, we know that ecological analogues to present industrial methods of sustaining human populations are both possible and viable. There remains for us only to internalize the essential limitations that are becoming so evident as to be foolhardy to deny. E. E. Cummings put it poetically, if paradoxically, when he said:

out of the lie of no
rises a truth of yes
(only herself and who
illimitably is)

To learn to say no in order truly to say yes.

NJT


New Alchemy

It has been recently pointed out to me by one of our readers of long standing (Malcolm Wells) that he had never realized that the Journal *is written, not by solicited contributors, but by New Alchemists themselves. It's true, of course, that occasionally friends like William Irwin Thompson, Evelyn Ames, Richard Falk, and, in this issue, Francisco Varela, have given us articles that we have included, but these are exceptions. Whatever its virtues and failings as a publication, the* Journal *is a work out of process. The same people who carry out the projects and do the research spend the fall or early winter describing and evaluating them for the next year's* Journal. *The same holds true for the graphics and the artwork. Although friends like Molly Bang, Alan Pearlman, and Fritz Goro have given us drawings and photographs that have cost them considerable effort and added immeasurably to the aesthetics, most of the artwork is still done by ourselves. Jeff Parkin and Jorge Bueno did the graphics for this issue. Hilde Maingay and more recently Ron Zweig have always been the principal photographers. And guest and New Alchemist alike work gratis. No one has ever been paid for a* Journal *contribution per se, simply because there was no money available to do so, although as New Alchemists it could be claimed to be part of the work to be expected for our salaries. The* Journal *springs directly from our experience and a conviction that our work is meaningless if it takes place in a vacuum. Also we feel there is a need for a nonspecialist publication that presents a panoply of ecologically related activities excluding neither precise scientific data, practical hands-on information, nor human interaction.*

This section, entitled New Alchemy, was created to try to avoid any kind of cultism or mystique developing around the group, although, as the article by Nancy Wright later in this section indicates, some of that seems inevitable. We wanted to give our readers a sense of who was behind the papers and reports, what the farm looked and felt like, and what the day-to-day work entailed. For this issue, anticipating new readers through our affiliation with The Stephen Greene Press, I have written a short history of New Alchemy, and in this year of nuclear alarm, tried to fit our work into the larger context of antinuclear activity. Nancy Wright, who was a volunteer in 1978, has sent us a summary of her thoughts on being an apprentice at New Alchemy. Its inclusion seemed appropriate to an issue with an underlying theme of the struggle both to learn and to unlearn in some very basic ways. Traditionally, this section also includes a report from Bill McLarney on NAISA, the New Alchemy center in Costa Rica. This year we again include a machete-wielding, mud-slinging recitation of Bill's adventures there.

Finally, in a slot that is usually taken advantage of by Bill and this time Christina, there is a space devoted to book reviews in which we try to draw attention to books we think important that people might not otherwise encounter.

As is becoming evident, the section is essentially a literary grab bag giving us a chance to say, as Christopher Robin did in the introduction to the World of Christopher Robin, *"Thank you . . . for asking us into your house. We've come."*

NJT

Photo by Hilde Maingay

New Alchemy: Creation Myth and Ongoing Saga

Nancy Jack Todd

There seems, these days, to be some controversy regarding the exact timing of both the beginning and the end of human life. How much more difficult it is, then, to pin down with any assurance the moment of birth of the collective life of a group such as New Alchemy. Was it when the original idea or ideas were first gropingly articulated, or when the idea was given a name? The date of legal incorporation as a nonprofit institute was certainly a visible and identifiable moment, but still there was little in the way of a physical reality then that one could point to and say that it was New Alchemy. We had to wait until 1971 for that actualization, nearly three years after what seemed the inception to those of us who had been a part of it for that long. Yet because with this issue of the *Journal* we begin a joint publishing venture with The Stephen Greene Press, and because like the Montague Farm Collective and the Whole Earth people, two other hangers-on from the sixties that have survived in the same incarnation, we are marking the tenth year of our existence, a retrospective of our evolution seems a fitting part of this *Journal.*

In 1969, John Todd, Bill McLarney and I were living in San Diego in California. Bill and John were teaching and doing research at San Diego State. One of their experiments involved the observation of the effects of pollutants on fish behavior, in particular, that of DDT on the brown bullhead, *Ictalurus nebulosis.* Their findings were disturbing. Minute amounts of DDT did not kill the fish outright, but jammed their social communications, disrupting established behavior patterns. What this meant essentially was that evolved survival patterns broke down and the group of fish were doomed to slow social disintegration, chaos, and death. Data like these were not only informative, they proffered a splendidly allegorical interpretation of the prognosis for ecological decay as well. Many other like-minded biologists at that time

were reporting comparable observations on the threat posed by industrial society to a wide range of species of animal and plant life and to their life support systems.

We began to hold seminars in our living room at which students or invited speakers presented papers on one or another aspect of the overall problem. Often people would stay afterwards, sometimes it was just John and Bill and I, and we would talk on into the night. I guess this could be called our coffee-house stage, although it was usually beer that we were drinking. Usually the ramblings of the conversation would eventually turn to what, if anything, could be done? What, if anything, could we do?

That same year we had another set of experiences of the kind that is usually called formative when John and Bill decided to take their biology classes on a series of field trips. These consisted of excursions into the dry hills of the border country just east of San Diego. We went there because we could prowl about freely on a ranch that had been rented by friends who hoped that, as a result of our forays, we might be able to teach them how they might be able to support themselves on the land without destroying it.

Their and our blythe expectations were quickly dimmed. The rambling, lovely hills stretched under vast reaches of bright sky were composed of hard, dry, sandy soil that gave rise largely to manzanita bushes, boulders, and the occasional live oak. We could find no source of water. Discouragement set in until John decreed that we simply did not know enough, that we could not, as he said, read the landscape. And so the second phase of the project began. We initiated a more intense study with every student undertaking to examine some part of the environment in detail. Soil and soil animals, insects, plants, shrubs, rocks, trees, and birds were collected, studied and catalogued. Very slowly, some patterns began to emerge. Midway up a small gorge we found a plant, the roots of which were known to need moisture, indicating the presence of a hidden spring. Below, where the gorge began to flatten out, there was a live-oak tree that grew in the midst of an association of plants that included miner's lettuce, which we knew to require good soil. Having stumbled at last on water and tillable soil, agriculture became a possibility. And if fish ponds were to be made to link the two, an agricultural ecosystem was within reach.

The story has an abrupt but pointed conclusion. As excitement began to stir over these newly discovered possibilities, the landlady arrived and, in a variation on one of the classic themes of melodrama, announced to our gentle, long-haired friends that she was raising the rent. The increase was more than they could afford and so they were forced off the land. Even before they departed, the bulldozers had appeared on the crest of the hill to begin leveling for yet another colony of California weekend cottages.

* * * * * * * * * * *

Before a creation myth becomes too firmly established, it should be mentioned that our beginnings were not all idealism. John has been a frustrated farmer since his childhood. Bill has been described, accurately I think, as a fish maniac. There is little that could have kept them from working with the land and with fish, sooner or later. And I was an unemployed peacenik, disheartened by the election of Nixon and feeling dread at the promise that the future seemed to hold for my children. For all children.

The accumulated experiences of the field trips and the late-night discussions slowly formulated themselves into a question which, in retrospect was, and is, the underlying paradigm of New Alchemy. We began to ask whether it was, in fact, possible to sustain human populations in ecologically viable ways rather than with the capital-intensive, exploitative, wasteful and polluting methods we now employ. And if so, how? At that time, it was an open-ended question for us.

I have my own highly subjective sense of when it was throughout this period that New Alchemy actually began. On a Friday evening that was the twelfth of September, 1969, I sat reading an article in *Ramparts* by Paul Ehrlich entitled "Ecocatastrophe." It was an imaginative account of the death of the oceans through pollution. The cover of the magazine graphically reinforced the story with a tombstone that was engraved with the lifespan of the seas. I finished the article, lowered the magazine and gasped, "John, we must do something." With that, I felt a familiar twinge, and the preliminary labor contractions that heralded the birth of our third child, Susannah, began. I was momentarily distracted from my other mission, but since then I have come to think of it as something of a twin birth. Susannah was ten on the thirteenth of September, and in roughly the same period, it can be approximated that New Alchemy is ten as well.

Our infancy was still largely made up of talk, studying, planning and the early stages of the paper phase. We became incorporated, as a nonprofit Institute, and were beginning to formulate concrete ideas for projects. Then in the summer of 1970, John and I and the children, and later Bill, crossed the country and resettled on Cape Cod. John and Bill began research at the Woods Hole Oceanographic Institution, and Bill began the monumental task of writing the text *Aquaculture,* which has since become the definitive work on that subject in English.

For the next year we were still mainly a paper reality, which anyone who has ever been with an organization from its inception will readily understand. Letters flew back and forth, supportive, helpful, some even containing small financial contributions. We began to cast about for serious funding and to feel increasingly the need for a land base. John wrote *A Modest Proposal,* which was published as the first New

Photo by R.

Alchemy Newsletter and was unexpectedly well received and widely read. This made our empire of papers even larger and we rented a small office in order to contain them. We were joined for a year by Annie Hinds who helped to reign over the ever-expanding flow and with her drawings set the format for New Alchemy publications. With friends from Cambridge, Multi Facet and Marsha Zillis, we built a small dome in the front yard of our house. We installed a children's swimming pool for the fish and planted the edges with vegetables. It was our first bioshelter.

That winter, Bob Angevine, one, if not the major, secret to our survival where so many other well-meaning institutions have failed, took over much of the financial administration. Earlier in the year we had gotten wind of an old dairy farm in Hatchville that might be available for rent. We approached the landlord, Bob Gunning. Negotiations went smoothly, we signed a lease and by May had moved onto the land.

The move was at once a culmination and a challenge. Having acquired a land base at last meant that the time had come to test our rhetoric. To transpose the theoretical into the tangible, to materialize an idea, is not necessarily easy. Until then, we had been trying to equilibrate what Stewart Brand called our talk/do ratio with backyard gardens and fish tanks in various people's basements. Bill McLarney created an amazing watery underground labyrinth for his fish one winter, but overall our efforts fell short of what we considered productive research. What we did with our move out to the farm and the chance to concretize our work was to structure our initial paradigm into three areas of basic human needs: those of food, energy, and shelter. The work with food branched into projects involving organic agriculture and aquaculture. Our energy research was involved with various ways of harnessing the renewable sources of the sun and the wind. The concerns for food and energy came together synergistically, almost of themselves, in the evolution of the form of shelter that is called the bioshelter, which is a solar-heated greenhouse that includes an aquaculture unit, and, in one case, provides living quarters for four people.

That summer of concrete beginnings, Hilde Maingay took charge of the gardens, and two young men, Earle Barnhart and Marcus Sherman, arrived in short succession of each other to become our windmill buffs. Later that fall, as we faced the cameras for the first time for a B.B.C. film crew, Earle and Marcus provided us with a memorably heroic image. They had been working for some months on constructing an electricity-generating windmill, and had spent countless hours high on the tower being buffeted by autumn winds, and feeling, as Marcus said, like Jonathan Livingston Seagull. The windmill, however, had yet to turn. The day of the filming had dawned gray and raw. Undaunted, they climbed the tower. Then, over the morning, with so providential a touch that it would be suspect in Hollywood, the sky cleared to an uncompromising blue and the sun streamed down. As the cameras whirred, with Earle and Marcus high and windblown on the tower, the windmill blades began to turn for the first time. Although much of our work is fairly repetitive and mundane, it does have occasional bursts of glory like this one. More often than not they are associated with the windmills which borrow from sailing ships a romantic quality of freedom. Since then, Marcus has gone on to found his own windmill company. Earle is still with us, but is now working on researching and developing permanent agricultural forests. He and Hilde were married on the fall equinox in 1977. It should be added that any accounting of our first year on the farm would not be complete without remembering that Rich and Yedida Merrill came from California to lend us their agricultural expertise and an enormous injection of energy and commitment.

. . . .

For a step-by-step account of our progress from that summer until the present, contingencies of space dic-

John Ryther of W.H.O.I. Bill spent over three years on the text which was nominated for the National Book Award in 1974. The following spring saw the arrival of Susan Ervin and Tyrone Cashman; Susan to stay and devote herself to the gardens and Ty to become a windmill builder, then move on to join the staff of Governor Brown of California, and, more recently, to become the president of the American Wind Energy Association. That summer, as the numbers of visitors swelled, Farm Saturdays, which had begun as a day of shared work and a convivial picnic, evolved to include a tour of the farm and extended explanation or talk on the work of the Institute. The fall brought greater harvests from both the gardens and the fish ponds, helping our feeling of confidence in our collective sense of self and in our ideas as well.

The following winter, Bob Angevine was forced to announce that the amount of administration that the group was generating, both from within and without, was more than could be endured, and Christina Rawley arrived to help him. She has since taken over the membership program and the editing of the membership newsletter. Tanis Lane and Denise Backus have since joined us and work on various aspects of the

tate that interested readers will have to refer to the first through the fifth *Journals,* while I confine myself here to landmark occasions and the entrances and occasional exits of the central cast of characters that make up the group.

The year 1973 was a year of digging in, getting the gardens and the fish off to a prompt start in the spring, and then seeing the work through to the completion of a full season. We were still very young as a group, and even the most ordinary event seemed something of an adventure. In September, we published the first *Journal,* which was illustrated by Camas Lott, who continued to do the covers for several years and established much of the visual style of the *Journal.* John and Bill decided that trying to carry what had become two full-time jobs was impossible and that financial security would always be elusive at best and so left the Oceanographic Institution to devote themselves exclusively to New Alchemy. That fall also saw the publication of *Aquaculture* which Bill McLarney wrote with John Bardach, now of the East West Institute, and

administration. Recently, Conn Nugent spent a year with us as co-director and fund-raiser, but found trying to raise money for a group such as ours, which defies orthodox categorization, so disheartening that he decided not to stay.

In the summer of 1975, with promise of support from the Canadian government in the offing, we teamed up with the redoubtable pair of David Bergmark and Ole Hammarlund who together form one of the most innovative and, by now, experienced solar architecture firms around. With the possibility of greater things on the horizon, they built, at New Alchemy, a small prototype of the bioshelters that we were to christen Arks, in the form of a family-sized, solar-heated greenhouse with a concrete aquaculture pond. Earle named it accurately, if not poetically, the Six-Pack, and so it has remained. Under Hilde's care, it has weathered every winter since without auxiliary heat and has produced satisfying yields of food and of seedlings. It was later that summer that Ron Zweig started to work with us and to quickly become pivotal to the aquaculture program, and Kathi Ryan arrived to add her gentle presence to the benefit of plants and people alike.

The year 1976 was a landmark year. Both of the Arks, the one of the farm on the Cape and the other,

Photo by John Todd

funded by the Canadian federal government, on Prince Edward Island, were completed. Both were opened with due ceremony that involved feasting, music, dancing and crowds of friends. Former Prime Minister Trudeau and then Premier Alex Campbell of

Photo by Hilde Maingay

Prince Edward Island arrived by helicopter to launch the Canadian Ark.

Later that same fall, the size of the yields from both the garden and the solar-algae ponds were as exciting as the more highly publicized openings. In her experiments with intensive vegetable cultivation in raised beds, Hilde found that she could grow enough food on one-tenth of an acre to provide thirteen people with three servings of vegetables a day throughout a year. Working with the solar-algae ponds, which are translucent, cylindrical, above-ground fish tanks, Ron found that he could attain fish yields greater than those of any other known standing body of water when the data were extrapolated to pounds per hectare, which is the standard international unit of measurement. By the end of the following winter, when both Arks had acquitted themselves with flying colors, we began to feel cautiously optimistic as to the answer to our original question of ecological alternatives. It seemed that the results of our research, especially when compared in scale with the funding and personnel that go into more orthodox paths, indicated strongly that a sustainable future based on an earth-kindly ethic and nonviolent technology is within the limits of the possible, indeed, well within our grasp. We are all the more convinced today.

It was at this juncture that we were able to interest the U.S. government in our work and received a grant from the National Science Foundation to monitor various conditions in the Cape Cod Ark, such as hours of sunlight, relative humidity, and the pH of the ponds. The goal, one that is now being achieved, is to create a mathematical model of the processes that take place within a semi-closed ecosystem such as this one in order that the processes be better understood and that any malfunctioning can be spotted quickly. With such a model, replications of the Ark can be created more readily, although we are equally committed to developing guidelines based on sensory signals that will be just as instructive for those who eschew the inclusion of a computer in their vision of a bioshelter.

Apart from funding in Canada for the Ark on Prince Edward Island, the National Science Foundation grant remains the only government money that we had received. Projects have since been funded by the Department of Energy and the Environmental Protection Agency. Otherwise support has almost always come through the efforts of private individuals representing foundations, many of whom, like Michaela Walsh, Robert Rodale, Stewart Brand, Edith and John Muma, and Frank Dobyns have long been friends and fellow travelers. Our members contribute substantially to our continued existence, and, in fact, have more than once carried us through periods of prolonged financial drought with their annual subscriptions and supplemental donations.

Over the years we have evolved a nonhierarchical structure that is largely self-governing and makes major decisions in a weekly meeting where all general business is discussed. Although most people have started as volunteers and worked for several months without payment, all permanent members receive equal salaries, regardless of type of work or number of degrees.

Photo by Hilde Maingay

Accompanying the computer into our lives came Al Doolittle and subsequently John Wolfe. Later Joe Seale, who is also conversant with computers, brought his engineering and analytical ability to the aid of our windmills and to our general repertoire of technological skills. With the most recent arrivals we are beginning to feel that we are approaching our limits to growth in terms of the size of the group. Colleen Armstrong is working with Kathi in the Ark. Later this year, J. Baldwin, one of the pioneers of alternative technology, will arrive with Kathl Whitacre who is a graduate in soil science and will work with our agriculture people. And all the while volunteers and apprentices come and go, some to remain an ongoing part of our extended family. Gary Hirshberg and Robert Sardinsky were volunteers that have been with us for so long that they became permanent part of us. Both of them have been vital to New Alchemy's political and educational outreach.

Over all the years of this rambling tale, I must ask our readers to envision, in flashback fashion, the simultaneous evolution of the New Alchemy Center in Costa Rica. Beginning as no more than the dream of one sunburned gringo in ragged tennis shoes who was quite simply in love with the Gandoca area, and as a result of Bill McLarney's dogged persistence and Susan Ervin's and later Kathi Ryan's support, it has become a small center for agricultural and aquacultural research that is dedicated to and an inseparable part of the local community there. Bill's writing on his adventures in Costa Rica and his thinking on development in Latin America are well worth the trouble of tracking down previous *Journals.*

By this time, we are fast approaching the present; the way things are now, as opposed to the way they were. This *Journal* is, in the main, concerned with the events of 1978. Because it is an annual, publication inevitably lags about a year behind what is actually taking place. The dovetailing of putting the *Journal* together with the yearly rhythm of the rest of our work was chronicled in the fifth *Journal.* The most exciting and encouraging news of the year just past came from Bill McLarney's and Jeff Parkin's work on the cage culture of the yellow bullhead, *Ictalurus natalis,* which is described in the Aquaculture section. Their harvests last fall at last justified their faith in this form of pond aquaculture as a source for protein in a hungry world. Jeff has been with us since early 1977. He came to work with Bill as a biologist but with Tanis has also become artist-in-residence and designed the cover and the graphics for this *Journal.*

Photo by Hilde Maingay

Now like Susannah, who began at about the same time, we are ten. We are older and, I hope, an edge wiser. We have grown and changed, but not that much. We are still a small band or collective of friends who work together in considerable financial insecurity, bound by a vision of a sustainable future and of our role in bringing it about as a kind of New Age Tool and Die Company that can help to create the software or biotechnic technology to realize that vision.

At the end of our first summer on the farm, I wrote:

> The world turned copper, the leaves fell and summer fades into the past. And yet, so much that was fantasy or plan or theory as the summer began has edged into the realm of reality. We have grown another generation of tilapia. We have planted and harvested our first gardens. Many people have come to see us and left us with something of themselves to give us a sense of being part of a force larger than ourselves that is growing now and is very real. The summer is gone; yet we have feasted and laughed and dreamed together. We have learned to love one another. We have begun.

It's not so different now.

Photo by Hilde Maingay

Farm Saturdays and Beyond

Since 1972, Farm Saturdays have been our major way, outside of our publications, of reaching out beyond our own immediate context and of sharing our ideas. Farm Saturdays have been through a number of incarnations. They began as a rather informal exchange of information, talking with people while working in the gardens or over lunch. When that became unworkable because of more visitors, we adopted the tactic of a tour accompanied by a fairly extensive explanation of the work. But after several summers, this in turn became impractical as it was hard for the again expanded population to crowd in and out of various buildings and still stay within range of the accompanying lecture. This led to our workshop phase, which involved structuring the day more tightly. We began, as we still do, at noon, with an introductory talk which is followed by a shared, pot-luck lunch. After lunch we offered a series of workshops in all the major areas of our research. We stayed with this format for another several summers, but as crowds continued to increase and our visitors grew more diverse in their interests, we sensed a need to revive the tour. We did so, and as of 1979, Farm Saturdays have become an amalgamation of the tour and workshop schedules.

We ask people planning to come to arrive by noon on Saturdays from May through September. As before, at this time there is a general introduction on the background and paradigm of New Alchemy's work. After this, everyone revives with lunch. We ask our visitors to bring food with them--a bit more than they are likely to eat themselves—and, preferably, something like bread or fruit or cheese or a casserole that is easily shared. This way there is almost always enough and people get a chance to meet each other as they serve the food.

The tours begin at one-fifteen, after a clean-up. There may be as many as four tours if that is what is needed to accommodate the number of people interested. Workshops begin at two-thirty and as many as four or five may take place at once. The topics cover our basic areas of research and, accordingly, are on various aspects of agriculture, aquaculture, energy and

bioshelters. The specific subject for each of these may vary from week to week. Pest resistance or agricultural forests may be discussed under agriculture, cage culture or semi-closed aquatic systems under aquaculture. At three-thirty there is a second round of workshops. Some of these may still be on our work, or a guest workshop may be given by our visitors on relevant topics like holistic medicine or antinuclear politics. There may be an additional workshop by one of the New Alchemists on a subject less specialized than most of the others, on the social and political implications of the alternatives movement for example, or on feminism and ecology.

Recently we have received the mild complaint from a few Saturday visitors that there is so much going on that it tends to be confusing. This could well be true. Rethinking the means of human sustenance is a fairly complex undertaking and for those newly introduced to the ideas, there is a lot to assimilate. We can only hope that people who come on Saturdays will find the information that they need and feel free to keep coming back as their time and the availability of gasoline permits.

Farm Saturdays notwithstanding, with time some of us began to feel increasingly uneasy about what we felt was a strong need for a broader educational effort that would cater to children particularly. With the arrival of Rob Sardinsky we had, at last, the right person for the job. Our first major and, to date, largest effort took place on Sun Day in May of 1978 when over six hundred students from Falmouth and Cape schools were given a tour of the farm. Subsequent to that day, which was really a glorious success, Sardo began a program of school tours. Since its inception in October of 1978 he has guided more than 1,500 students from preschoolers to postgraduates about the farm. Sardo has a talent for making information about natural systems and biological processes accessible and relevant even to very young children. Although we remain painfully aware that this is only the smallest drop in the bucket in terms of the re-education that will have to occur with times changing with such great rapidity, we feel very much better about having made a start.

Photo by R. D. Zweig

Photo by R. D. Zweig

No Nukes

Nancy Jack Todd

As the seventies draw to a close, the scent of incipient change strong in the air, and we begin, mentally at least, to fasten our seat belts for the eighties, the unresolved issue of nuclear energy still looms large before us. It is too soon to know whether the near melt-down at the Three Mile Island Plant near Harrisburg, Pennsylvania, in March, 1979, will prove to have been the turning point in the energy debate. Perhaps that is too much to hope for this soon. What is becoming undeniably evident is that events in the energy arena are moving at an enormous speed and that the decisions and policy that are being made will affect our lives drastically and for a long time to come.

New Alchemy's position on the subject of nuclear energy is probably too obvious to need explaining. We have always considered it self-evident that the fact of its existence was in itself an antinuclear statement, but a remark from Margaret Mead several years ago convinced us that support of the antinuclear movement was as vital to our work as was solar design. She and John Todd had been lecturing in the Social Ecology Program at Goddard College. Before leaving, Dr. Mead waved her stick at the windmills, domes and fish ponds that dotted the Goddard landscape, nodded approvingly, then added, "But, you know, it won't do a bit of good if we don't stop nuclear power."

As ever, she was right on target, and we stretched to incorporate that reality. Devotees of the sun that we at New Alchemy may be, we still live in a world where it is not yet possible just to cultivate one's garden, as Candide advised. Even though solar research is making great strides, at the present over one half of the research scientists of the world are still employed in military research and development, and a significant proportion of this research is used in developing the technology of mass destruction and repression. Steve Baer summed the situation up most succinctly when he said:

> A dog that hasn't been chained long forgets. It rushes across the yard and then—bang. Today when people become excited about the future and involve themselves with new uses of technology they often get carried away with hope—then bam—they think about the atomic bomb, the H bomb, the ballistic missile. Today, like the dog, we all have the chain on us. There is nothing very marvelous going on unless it is something to untie that chain.

The best handle that we have to date for focusing public attention on the larger question of the arms race is with the apparently more immediate and visible issue of nuclear power.

The first step in active resistance for any of us at New Alchemy came in 1976 when Christina Rawley joined the Clamshell Alliance and was arrested for occupying the site of the Seabrook plant in New Hampshire. A few weeks later, at the opening of the Ark on Prince Edward Island, we had a chance to express our views to then-Prime Minister Trudeau. His reply was to the effect of, all right, but what else do you suggest? His question further reinforced our own conviction that the issues are conjoined or that the antinuclear and alternative technology movements are two sides of the same vision.

Since then, many of us have gone to rallies, meetings and demonstrations. Most of these were concerned with Seabrook but increasingly we are focusing on our own down-home reactor at Plymouth. Pilgrim I has the not too reassuring reputation of being one of the oldest and leakiest plants in the country (and there are only two bridges on and off Cape Cod). And to add to our grievances, Pilgrim II is being planned. It's becoming harder and harder to cultivate one's garden at all.

In the fall of 1978, with the Seabrook plant under construction, we began to hear more of plans for a land and sea blockade of the plant's reactor pressure vessel when it was to be shipped from New Bedford, where it had been constructed, to the plant site. Rebecca Todd started a local Clamshell affinity group that was made

up of a mixture of local people and New Alchemists. They took training in civil disobedience and became thoroughly conversant with the arguments for and against nuclear energy. After many months of preparation and vigilance, waiting for the call that would announce the departure of the reactor pressure vessel from New Bedford, the moment came with the ring of the phone on the evening of the eighth of March, and our people, their bags long packed, were swallowed up into the night. By early afternoon of the next day, those of us keeping vigil at home received word from John Wolfe that Rebecca and Rob Sardinsky had been arrested and charged with disorderly conduct. The local support system, headed by Christina, rallied with bail money and they were released later that day.

On March 28, the surreality of Three Mile Island began. I spent the first day or so wondering what that odd, numb sort of feeling around my heart was, and with time recognized it as terror. I know that individual reactions must have been as varied as the millions of people who were exposed or endangered by the radiation, but I haven't felt so directly and helplessly threatened by events utterly outside my control since the Cuban crisis in October, 1962, as Russian warships steamed steadily and it seemed irrevocably toward Cuba. As the most immediate danger at Three Mile Island apparently began to abate, with sequential irony, the appointed date to launch the *Ohio,* the Trident-missile-bearing nuclear submarine from Groton, Connecticut, arrived. As President Carter was represented by Mrs. Carter and the John Glenns, the antinuclear people here were represented by Rebecca and Julie Genatossio. They chained themselves together to block passage to the naval shipyard and again they were arrested. While President Carter declaims the cause of human rights abroad, some of our own young people are prisoners of conscience in their own country.

The ecological damage left in the wake of what was not quite an official disaster may take years to assess. At the time of this writing it has just been reported that the depth of radioactive water on the floor within the plant had been underestimated by several feet. The amount of radioactive steam vented into the atmosphere and the effects it will have on human and environmental health are unknown and no doubt will be so for some time. One of the few givens is that official statements will continue to equivocate as to what actually happened. Where will all that water go? How much has leached out already into the Susquehanna and on downstream to Chesapeake Bay?

In terms of social ecology, the aftermath has been an exponential increase in general awareness and concern. Nuclear power has become, at last, a public issue. Considerable credit is due unquestionably to Jane Fonda and her film, "The China Syndrome," the amazingly fortuitous timing of which reinforced the

Photo by R. D. Zweig

message of Three Mile Island. Equally fortuitously, assistance is coming, albeit still quietly, from financial projections, an area from which we do not frequently recruit allies, as the economics of nuclear power begin to look increasingly bleak. Certainly Babcock and Wilcox are not faring too well, and increased demands for safety in other plants are going to escalate building and operating costs to hopefully prohibitive levels in the fairly near future. The all-too-obvious hedging on the part of the authorities has weakened public confidence in the credibility of officialdom. This in turn may further serve to keep the nightmare of nuclear fusion at bay.

With glimmerings of hope on the nuclear front, we could well find ourselves on the horns of yet another dilemma. Even as the antinuclear forces gain in strength and become increasingly accepted, the claims of some of the proponents of nuclear energy grow concomitantly in stridency and, one assumes, conviction. We would do well to keep in mind the possibility of a backlash. What more logical culprits for a failing economy than the opponents of continuing growth? In several recent popular works of fiction, including Arthur Hailey's *Overload,* and *The Wanting of Levine* by Michael Halkerstaur, environmentalists and antinuclear activists are portrayed as irresponsible and uncomprehending or as villains. As the last article in the Explorations section, by Francisco Varela, describes experientially and so well, the danger in sharp and rapid polarization of opinion is that it can lead to a complete breakdown in communication between partisans on both sides. Inadequate thinking or, in his words, poor epistemology will most often result in ill-conceived behavior. If the nuclear issue is to be a major pathway to a sustainable future, then it is crucial to avoid unnecessarily alienating tactics. Intractable dichotomy is likely to lead to the frustration and potential violence of mutual incomprehensibility.

Photo by Hilde Maingay

Notes of an Alchemist's Apprentice

Nancy Wright

It is difficult to encapsulate a revolution, personal or otherwise. It's even harder to explain something very close to your heart without sounding foolishly sentimental.

In 1978, in the spring of my sophomore year, I wrote a letter to New Alchemy. In it I expressed frustration and dissatisfaction with my education at a supposedly prestigious university. It seemed to amount to a stale compendium of lists, facts and grades in a framework of competition and social pressures. I was being spoon-fed (force-fed?) "information" that seemed isolated from either thinking or reality. Worst of all, I was coming to accept it passively, living with a vague dissatisfaction. Some call it atrophy of education, for me it was atrophy of the brain. The golden temple of academia wasn't helping me to learn, even to be a productive individual in society. At most I would become a marketable commodity, a graduate from a big-name school. Money. Prestige. I watched my fellow robots to see if they felt this decay of our education, but I saw them lining up, comparing clothes and competing for lucrative jobs in a tight market. I wrote to New Alchemy to see if I could break through this educational apathy. To save myself. To start caring again. I wanted very much to have faith in something. At that time New Alchemy represented almost a magical solution.

Almost a year later, I have found that faith I was looking for. My mind is working again and my education becoming meaningful. This is because through New Alchemy, I have gained a new attitude about people, myself, and science—my field of study.

In August I began as a New Alchemy volunteer, as an apprentice with the semi-closed aquaculture program. I thought at first that perhaps New Alchemists were a mythical lot, a step or two removed from real people, free from problems, virtuous, and for some reason, all vegetarians. I was petrified that someone

might find out that I indulge in junk food or, at times, wear make-up. For some reason, I had strange preconceptions, ones that I find others share. Much to my relief, I found the Alchemists to be a diverse mix of extraordinary but very human people. They were neither the "New Age" gods and goddesses, nor the irresponsible freaks various people had pictured for me. The difference lay in their attitudes, not their affectations. In fact, the most tangible difference I could pin down was that they used a different slang than I do with a flavor of the sixties not heard on campuses today, the slang I associate with college activism. I guess, deep down, I am jealous of the spirit that sixties students had. I had always believed that college ought to be where you got all fired up and showed your fervor rather than the alligator on your shirt as they do today.

The sheer number of projects going on at the farm impressed me. I had been exposed to little in the way of alternative technologies and I felt as uninformed as is possible. I wondered how many other people are as oblivious of the existence of such things, from windmills and solar greenhouses to fish and kohlrabi. The endless flow of questions began. How do these things work? How will they affect society? The economy? The environment?

Gradually, the concepts behind each project began to come into focus. This was especially true with the aquaculture systems with which I was involved. In my mind, the solar-algae ponds progressed from a random bunch of fish, algae and fiberglass, to an interconnected, living web—a complete entity of interdependent factors and functions. My questions multiplied.

I was fascinated by the social aspects of New Alchemy—another set of interdependent factors. There are strong pressures due to lack of funds, equipment, and hours in the day. There is the ongoing stream of questions from visitors and outside seminars and talks that are given. Volunteers come and go and must be trained, yet each is treated with tremendous warmth, a fact I shall always remember and cherish. It is by no means a nine-to-five job. Pressures and emotions can often run very high. Yet there is a cohesiveness and a balance within the group that enables it to deal with all these things. It is a strong, and strongly protected, sense of community; a fine-tuned ecology (in the classical sense of the word) that is maintained.

Wednesday meetings, which the group lets volunteers attend, allowed me to see some of the structural bases and goals of New Alchemy. I saw why things were the way they were, whether it was finances or how the Ark was closed at night. I could stay informed, but more importantly I could understand and deal with frustrations that I, as a volunteer, or anyone else might have to deal with. I feel this is essential when working closely with a number of people.

In the weekly discussions, the goals and their underlying justifications that give a sense of purpose and direction for the Institute become apparent. Everyone contributes toward this end, fortifying the group unity. Having goals or working toward an end is something we seem to have lost touch with in many aspects of society. Often, if we have the means to do something, we plow right on, simply because the technology is there. The ends are neglected till they arrive. In the recent past, many of these new arrivals, like nuclear power, have been fraught with unforeseen problems. We fail to question motivations and look at ramifications of actions. The New Alchemists try to embody this with their ongoing assessment and group discussion policy. U.S. government, take note.

My actual work as a volunteer varied in amount and complexity. Regardless of its sometimes menial appearance, I was never treated as an insignificant "gofer" in the aquaculture group. No one was ever condescending despite my negligible background in some areas. I was, instead, taught patiently and encouraged to learn. What was wonderful (and refreshing) was that I enjoyed my work, from feeding fish to counting algae. Through daily exposure, I found myself awed by the complexity of the organisms, the systems, and simply of life itself.

My stay at New Alchemy was a period of academic as well as personal growth. The ideas and beliefs I was exposed to affected me in a number of ways. Since dissatisfaction with my education had been a prime motivation for going to New Alchemy, I became aware of some alternative and different ways of better utilizing education. Two concepts to which I had never been fully exposed are those of thinking and reality. I had been educated through a system of repetition and memorization, with an emphasis on specialization. Even early on, educational goals were either professional or job-oriented. Now I am finding that I do not have a well-developed way of thinking and have no idea about many basic things. There are two things that could be done to remedy problems like this—or, more hopefully, cure them.

The first is beginning to be implemented at lower levels and involves giving the student a broader educational base from which to work. This includes, or should include, social sciences, humanities and natural sciences, and just current fact. We should be taught other modes of reasoning and thought, and their history. A student should have a picture of the human being as a social and biological organism and as part of a larger entity as well. Then perhaps each of us could internalize a set of values or orientations, because today we are called upon to make such difficult choices and to think about the future in an incredible way. Science and technology have reached a point at which we must carefully question each step we take. Judgments and value decisions have to be, and are being, made. To make such decisions we must be familiar

with moral, ethical, social and economic issues as well as the more practical and "scientific" sides. No one person can be an expert in all fields of thought and action, but the awareness of the existence of other things, of the "whole," gives us a stronger framework to work from, a belief system to hold on to.

The second educational factor is much more concrete. People need exposure to real things and situations, and the chance for practical experience. My exposure to the aquaculture systems at New Alchemy gave me a strong sense of what ecosystems and ecology are. I cannot begin to compare this with a written description. This almost innate feeling now gives me a better appreciation for any other systems, biological or social. If each of us could experientially gain a comparable sense, we would have a greatly expanded ability to understand and to work. We could then make use of a broad background in a theoretical sense, yet link it to reality. In terms of environmental education, for example, such a technique would stimulate a higher level of public awareness and an understanding of major environmental questions facing us today.

Taken together, tools of background and depth and exposure to "reality" would develop the ability for constructive, careful thinking, something that people don't seem to learn today. With the linking of the classroom with the real world, education would become a "whole" entity instead of a scrapbag of fragments and facts. Thus equipped, an individual could face and question the things going on around him or her. We must go beyond caring and become thinking, aware people.

Finally, and more intimately, my experiences at New Alchemy led me to personal growth, to the education of my self. It always seems to come down in the end to "myself." Perhaps this is unfortunate, perhaps not. Ultimately, one still must deal with one's self. This seems to demand thought and reflection combined with input from many sources. For me, New Alchemy was an ideal environment for personal growth. There were sensitive people with stimulating ideas. I had both a dynamic place and time to think. I became aware of choices and decisions I could make, priorities I might have to choose, and roles I might or might not fill. This was exemplified by the women at New Alchemy. I saw and was friends with women who were very consciously dealing with their changing roles in society and in their own lives. There was a spirit that I had never felt before, a pride in being who and what they were as vital, contributing individuals and as women. It was, in my mind, not only a manifestation of women's liberation, but people's liberation. This and other experiences as well opened my eyes to new satisfying and meaningful possibilities for me.

The net result of this flood of thinking, this "internal revolution" (at least that is how it feels to me) is that I am back in the same institution in which I started. But now I can see it as a bounty of resources and of opportunities to learn and explore in many directions. Many of the apathetic and social problems still exist. They did not evaporate, but the opportunity for an education is there for the taking. To do that is a matter of priorities, and dealing with, not fighting, the hassles of college as it is today. Granted, it is a compromise, but the trade-off is worth it. I have regained my enthusiasm. I have energy and motivation again. I have a belief. People can turn their energies toward creative, useful ends. They can think and learn. They can deal with technological problems on a human scale. I found that spirit at New Alchemy.

Book Reviews

Poirot, Eugene M. 1978 *Our Margin of Life.* Acres U.S.A., 10227 East 61st St., P.O. Box 9547, Raytown, Missouri 64133. 139 pp., $3.50.

Photo by Hilde Maingay

reviewed by *Bill McLarney*

I first became aware of Gene Poirot as the inventor of Rube Goldberg fish-harvesting contraptions that work. I later discovered that in the more than 50 years since he first began farming with "no education, just a university degree," he has done many things that work. He began, and still farms, on 1,900 acres in southwestern Missouri. He has allowed 800 acres of this expanse to remain as one of the last stands of virgin bluestem prairie on the continent. One thesis of this book is that it is that 800 acres which has taught Gene Poirot how

to farm. And now he asks his prairie to teach us, not necessarily to farm, but at least to see more clearly how nature relates to society through the farmer.

The book is like old-fashioned farming, at once practical and romantic. Poirot's thought can be as basic as the need for food or as romantic as a prairie night in May. It is on such a night that he invites us, "Come walk with me in my virgin bluestem prairie on this night in early May. Listen, while it reveals its past. Learn, since it teaches the lesson of survival. Take hope from the beauty of its flowers and renew your faith from the murmur of its creatures." During a 12-hour period we watch the cycle of events on that prairie and listen while Poirot alternately addresses a sharp-shinned hawk who lives in an old elm by the bank of Coon Creek, Lady Moon, or us, his guests. Through the author's relationship with the hawk and the moon we are given not only an appreciation of the prairie ecosystem, but sound agricultural advice, a suggestion for a national agricultural policy, and a land-based philosophy of life.

Poirot was one of the first of the "scientific" farmers and one of the few wise ones. He has realized that science is a tool for the farmer, not a panacea. American agriculture today seems to take the attitude that a phenomenon *begins* to exist only when science analyzes it. And we tend to behave as if science and its stepchild, technology, could be used not only to alter natural systems, but to mutate the laws by which both natural and human-modified systems operate. But Poirot says, "We humans are one product of the Great Scheme of Things. Science tries to determine how we got here, where we fit and what we may do to survive. In fact we *did* survive because of the Scheme long before we had much part in its performance. This in itself is reason enough to believe its teachings as we can observe them in a general way, without waiting for science to come up with all of the answers, for we cannot wait long and be sure of survival." The book is filled with examples which show how Poirot's application of scientific knowledge rests on a firm foundation of experience, and how his use of scientific insights reveals whole new vistas where intuition and perception, as well as the rational powers, can play. I was struck by the thought that humanity may one day conclude that the real purpose of science was to lead us back to a more sensual and intuitive relationship with nature.

Poirot's attitude toward technology is made in his references to chemical fertilizers. He is not a doctrinaire "organic" farmer, but a practical farmer who recognizes the limitations of a technological approach to natural systems. Speaking of the contemporary use of chemical fertilizers, he notes, "In the last few years we have returned more plant food than at any time in our history, not to improve the soil but to meet the immediate needs of the crops we grow . . . but we are still losing more plant food than we are replacing" (due to our disregard for living organic matter in the soil). He describes his use, in the early days of his farm, of limestone and superphosphate in conjunction with sweet clover to restore prairie soil. By drilling the chemicals into the soil with the clover seed, they were held in place long enough to help the young clover roots get started on their part of the job. The cost of the chemicals used in this manner was 15% that of the fertilizer technique which was recommended to him at the time. His use of chemicals was but one step in a long-term process which has resulted in virtual elimination of chemicals, made his farm among the most productive in the United States, and earned him a bevy of awards from both agriculture and conservation groups. Unlike many of his contemporaries he did not lose sight of the fact that "taking minerals from mines is a temporary measure, not a solution to the problem of recycling plant foods."

Poirot makes an economic case for his methods of soil restoration. "The Farmers State Bank in Lockwood, Missouri" (not far from Poirot's home in Golden City) "showed a significant growth after financing soil and water restoration for ten years. In the last seven of these years, the bank grew an average of over $1,000,000 per year, to a capitalization of $14,300,000. . . . In 1922 some economists suggested that this land should be abandoned; it was, they said, worn out and could never be farmed in a profitable manner."

But economics, like science, is only a tool in the author's kit. He castigates humanity's "eagerness to get money rather than a permanent source of life." And he pities the "banker with a hoard of indigestible gold living now by the charity of those who would share with him the margin of fertility still remaining in their farms."

The notion of "margins" is central to the book. The hawk is just enough faster than the quail to be able to catch his supper; that is part of his margin of life. The hawk, and the quail, upon death are returned to the soil. That is part of the margin for plants, for more birds, ultimately for us. We owe our existence to "an accumulation of margins at a progressively higher level of life." And, argues Poirot, it is an extra margin provided by the farmer—what we call "abundance" —which ultimately determines the quality of our lives.

In practical terms, the central point of the book is that modern agriculture, and the philosophy which determines it, are eroding our margin of life. "Those who have implicit faith that the law of supply and demand will correct the decadence of our soil resources should note that the same law in other nations has hastened soil destruction, with the result that human diet had to change from animal proteins and fats to vegetable proteins and starches." Poirot asserts that "man's failure to recycle the resources he uses, adding

more where they are needed, and keeping recycled resources and additions within reach of new life at a time and place where nature can use them, *is the farm problem* all over the earth."

This leads him to a suggestion for a national farm policy radically different from the present one. While Poirot apparently has more faith than I in the capacity of our federal government and our economy to discern and take the right course, his ideas are certainly worth promoting. He suggests that "in our nation, which tries to make supply and demand work, the answer is simply to make a market for resource restoration that operates in direct competition, price-wise, with the market for buying agricultural products, which according to our present methods is destroying and misplacing resources."

What this would come down to is to make the customer foot the bill for soil restoration and resource conservation. In this day of Proposition 13, that may not be a popular idea. Yet I would submit that Poirot's suggestion cannot be considered without being balanced against what we are asked to contribute to inflated defense costs, destructive energy programs, space exploration, questionable highway construction, hidden industrial subsidies and general bureaucratic inefficiency.

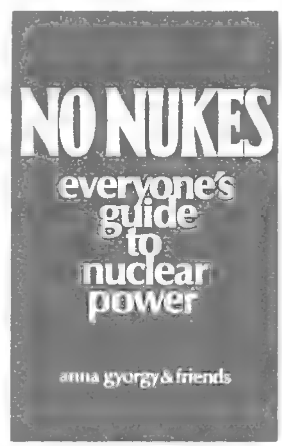
Poirot proposes some pretty radical ideas. He believes farmers should be rewarded for producing the most nutrition, not the most "food." He suggests that, since the owner of a phosphate mine or an oil well is entitled to a depletion allowance on his taxes, all the more so should the farmer receive one for soil minerals, so that he can afford to go ahead with soil restoration. He asserts that soil is capital and crops interest, and until our agricultural policy takes cognizance of this, farmers will be economically pressured to take a destructive course. He believes that the only legislation which will effect soil restoration and conservation is legislation that rewards the good farmer by offering incentives, rather than intensifying competition, thus punishing the bad farmer.

His suggestions for a national farm policy are of course directed to the seats of government, but they are also addressed to us. "I am your farmer," says Gene Poirot. Here is his challenge: "If we are going to try to solve the farm problems for abundant production, plus environmental problems of clean air and water, flood control, wildlife conservation, extra recreation and the preservation of natural beauty, we had better employ the farmer to help us. . . . I have demonstrated what can be done over a period of fifty years. If you want it on a national basis, get busy and push for it."

So far I seem to have reviewed the technical and political aspects of *Our Margin of Life*, while paying only passing notice to its poetry and philosophy. This is not meant to be in proportion to their worth. It is merely a confession of my inability to do justice to them. When Poirot looks ahead to the day his hawk will die, and describes the event in terms of its place in the larger scheme, one may weep for the hawk, but at the same time one will see the beauty of the whole. And one will realize that the author makes no distinction between Gene Poirot the technician and Gene Poirot the nature poet. If all the people responsible for our agriculture had such a unifying vision, Poirot could write only poetry, without exhorting us to husband our resources.

There is really only one thing wrong with this book, and it is a familiar problem. "We" will read it and love it. But it is not clear that it will be read by "them." *Our Margin of Life* needs to reach the modern farmers and bankers and politicians and policy makers and informed voters who steer the course of our agriculture and who ordinarily read only what agribusiness wants them to read. For they are the ones Poirot is challenging directly. Fortunately the writing is such that the book will appeal to anyone with an aesthetic sense or a feeling of responsibility for the future, whether or not he or she has ever been concerned with agriculture. The challenge to *us* --and I include the book's publisher—is to get this book, and this philosophy, to these readers.

Gyorgy, Anna, and Friends. *No Nukes: Everyone's Guide to Nuclear Power.* South End Press, Box 68, Astor Station, Boston, Massachusetts 02123. 478 pp., $8.00



reviewed by *Christina Rawley*

Over the past decade we have worked with many other groups similarly dedicated to the creation of a sustainable future. At about the same time as New Alchemy began working on the farm in Hatchville, a small commune settled on land in Montague in the western part of Massachusetts almost diagonally across the state from Cape Cod. As New Alchemy has focused on the research and educational aspects of

appropriate technology and land use, the people at Montague Farm have been primarily concerned with direct-action political organizing against our number one dragon, nuclear power.

Anna Gyorgy, the author of *No Nukes: Everyone's Guide to Nuclear Power,* lives on the Montague Farm. She began organizing the No Nukes movement when a twin nuclear plant was proposed for the town of Montague. This threat made her aware of the problems with all atomic power plants. She is a founder of a local citizens action group, the Alternative Energy Coalition, and of the Clamshell Alliance. As a member of the Clamshell Resource Committee, she has served on regional energy task forces and has spoken at countless rallies and meetings locally, regionally and internationally. This seminal and continuing antinuclear research activity makes her well qualified to write "everyone's guide."

No Nukes is an excellent educational tool for anyone concerned about the nuclear power issue. It contains nearly 500 pages of facts about nuclear power, its history, technology and economics, as well as its social and political implications. A veritable reference encyclopedia, it was produced with the help of eleven friends, experts, and people directly involved in the no-nukes movement around the world. It is written in a clear style which can be easily understood. The type face is easy on the eyes and is printed in double-column textbook style. Six graphic artists prepared the hundreds of illustrations that are on nearly every page. Each chapter is backed up with pages of footnotes.

At the end of the first chapter is a No Nukes dictionary that I referred to constantly this spring during the near melt-down of the Three Mile Island nuclear facility. On page 415 there is a reference to public political opposition to the Three Mile Island facility even before the accident, reporting that in an Appeals Board meeting it had been said that the license for TMI II had been issued illegally and that the plant should be shut down!

The second section on economics guides us through the nuclear power structure and the impact of the industry on economic growth from uranium reserves to power-plant construction. With regard to the fallacy that more nukes mean more jobs, Ms. Gyorgy says "money invested in electricity generation creates fewer jobs than money invested in almost anything else."

The last half of the book is devoted to solutions. After defining the problem of nuclear power in the first half we are given ideas about what can be done. A section called "Some Alternatives" begins with the practicality of conservation, of improving efficiency of energy use while conducting research to develop renewable energy sources. Strong consideration is given to small-scale, decentralized energy systems, controlled by communities and individuals. Alternative energy sources such as passive solar, hydroelectric, wind, biomass, biogas, alcohol fuels and wood are all described with a summary of their major benefits and attendant problems. Some "high" tech applications such as photovoltaic cells, photothermal and ocean thermal conversion, geothermal, solar satellites and fusion are also described with a warning:

> Just because a particular method of producing energy is solar powered, it is not necessarily "appropriate." What we must ask is: Whom does it serve; who controls it; and what are its costs in social, environmental, and financial terms. As we approach and begin to enter the solar age—and enter we must—let us not be fooled into thinking that solar technology is inherently smaller scaled and therefore "better." Solar systems can be very high-technology stuff. They can be complex, centralized, expensive—and unnecessary.
>
> As we enter a new era, it is appropriate to question the standards by which the new energy sources will be developed. Will it be for maximum profit, for private enterprise, including investor owned utilities? Or will the solar age have values and goals besides profit: things like the quality of life, health and safety, creation of good jobs, maximization of public and local control. . . . Choosing the appropriate alternatives is not an economic problem but a political and social one.

The footnotes in this section again show the detailed research efforts of the whole book.

Because over half the book describes alternatives and efforts to transcend the nuclear culture, while we are given the grim picture of nuclear power on the one hand, we are offered other possibilities on the other. The book is not depressing. It is a result of Ms. Gyorgy's and her friends' dedication to the struggle against nukes and oppression and for the liberation of clean energy as though people mattered.

As a feminist, decentralist and no-nuker, Ms. Gyorgy has made a strong statement through the process by which this book evolved. Working on a very low budget and instead of traveling around to gather information as is customarily done, she bought stamps, wrote letters, and contacted people from all corners of the world who wrote of their own work. Many women such as Liz Apfelberg and Jane Swanson of Mothers for Peace in San Luis Obispo, California, and Native Americans like Thomas Banyaca of the Hopi tribe contributed to the final section of the book, which is made up of reports of the activities of various antinuclear organizations. The writing style throughout the book is easy. Even the sections dealing with the technical aspects of the issue are written in such a way as to demystify the system. And that's part of what it's all about.

In conclusion Anna Gyorgy says,

> Educate, agitate, organize . . . The best way to fight nuclear power is to study up and start talking . . . Look into solar alternatives in your community. Practice energy conservation and support local attempts to take over power production and distribution. Check out the sources of radiation nearest your home. Write letters, join or form an activist group. Be aware and be active. Demonstrate. Our future depends on it.

Photo by Hilde Maingay

At the Threshold of Winter Looking Towards Spring

The seed, the life-bearing seed,
Is already in the ground, hidden
From those who see only the fields
And imagine that summer is forever.

Not so, dear friends. Summer has gone
And what you live with on the surface
Is not more than the husks of the past,
Ready to rot and be turned under.

Who wants to know that winter is coming?
Yet in the mountains of Iran snow
Has already fallen—the same snow
That will cover us all this winter.

Flakes of terror, chaos, the white death,
Are falling now on all our cities,
But melting quickly, before anyone
Is constrained to acknowledge the fact.

"Times are bad, but the stock market
Is almost keeping up with inflation
And there seems to be oil and gas
Enough to see us through the next election."

So you say now, but when the House
Of credit cards collapses, or is blown
Down by a nuclear blast, one black hole
Is as good as another to pass the time.

In the midst of winter the most difficult
Task for those who guard a certain vision
Will be to remember, to remember
Not the past, not the future- -the present.

That pulse is not yet felt or heard
Except by those it animates, who breathe
A different air, the great connector
Of today's underground, germinating tomorrow.

Without winter, no spring.
Without death, no birth.
Without suffering, no compassion.
Without love, no joy.

So let me fall into the ground and die.
Whatever is true will come up in the spring,
And that which isn't will fertilize what is.
In the womb of the Mother, nothing is wasted.

James George
6 May 1979

Costa Rica–Fish Culture

Bill McLarney

It is a cliché that nothing happens on schedule in rural Latin America. This report verifies that cliché. I had hoped to be able to write of the first New Alchemy fish harvest in Gandoca. Instead, I can offer only a tale of slow progress in the face of obstacles and setbacks. At first the realization of what I would have to write for this *Journal* bothered me as much as the lack of a giant fish crop; presumably our readers want more than amusing stories. But then I thought of the correspondence we get about NAISA work, and the visitors who arrive at the Cape bound for or coming from their own tropical experiences. And I realized that, though our aquacultural responsibility is primarily to the campesinos of Costa Rica, they do not read this *Journal*. Among our English-speaking readership are many who are working or will work in the developing nations. Some of you will experience technical aquaculture problems, but all of you, in or out of aquaculture, will encounter the kinds of nontechnical predicaments we get into in Gandoca. I hope my accounts will help you grin and bear it, reassure you that there is a solution, and maybe even suggest a solution now and then.

At last writing (May, 1977), our system of two ponds with drainage ditches was perhaps 75% completed, and I was on my way back to the States. At that time, the plan was:

1. the local work crew would finish the construction hopefully before the start of the rainy season;
2. Fish culture trainee Oscar Cerdas would then spend a month in a "work-study" situation at an established fish culture station of Costa Rican government,
3. on his return, Oscar would bring, *Tilapia nilotica*[1] brood stock

[1] The current correct taxonomic name for this fish is *Sarotherodon niloticus*. However, since it lacks a generally accepted common name, and the terminology *Tilapia nilotica* has served for many years, we will adhere to it here

to be placed in the "reproduction pond" (See the fifth *Journal* for a description of the components of the system.); and

4. on my return to Gandoca in January, 1978, we would make our first small harvest and stock the larger pond with young males from the reproduction pond.

Well, as reported in a previous *Journal,* step 1 went off on schedule. That news came to me in a letter, but I really was unprepared for the excellence of the finished system. I was particularly impressed with the crew's ability to lay out a functioning drainage system on apparently flat ground, with no measuring instruments whatsoever. We have approximately 80 meters of ditch snaking around the ponds, and it all flows the way it is supposed to.

The pond outlets have a dual drainage system. Large volumes of water, such as may occur in the rainy season, are handled by an L-shaped plastic pipe with a removable top section. This serves to draw the ponds down to about 1½ feet at the dam. More gradual or more complete drainage may be achieved with a double set of Rivaldi valves, a Paraguayan innovation which should be known to all small-scale fish culturists.

Enough malanga (*Colocasia* sp.) had developed from the plantings made the previous February to begin feeding fish. But where were the fish? I should have known it would not be easy to get the stock we needed when it took four months of intercontinental correspondence to get Oscar into a fish culture station. In both cases we owe the solution to the Director of Aquaculture in the Costa Rican Ministry of Agriculture, Herbert Nanne, Jr.

Some time after my arrival in Gandoca, we arranged through Sr. Nanne to purchase 400 young *Tilapia nilotica.* (All available breeders were quite large and would probably not have survived shipment.) The fish were to be netted at the Fabio Baudrit field station near Alajuela, bagged, driven to Juan Santamaria airport, and air freighted to Limón. At Limón airport they would be picked up and trucked an hour to Puerto Viejo. There they would be loaded into a dugout canoe equipped with a 6-h.p. motor for the voyage to the bar at the mouth of the Rio Gandoca—an hour and a half in good weather, impossible in bad. (As a safeguard against the latter possibility, it was necessary to have on hand some plastic screen, lumber, and a carpenter, in case it became necessary to float the fish in cages overnight in a creek in Puerto Viejo.) Assuming they reached the Gandoca Bar, a horse would be waiting to carry them the last half-hour leg of the journey.

Do try to imagine the logistics of all this in a place where few people have access to a phone and all messages must be relayed in person or put out over commercial radio. Irritating delays are inherent in this sort of thing. Only "irritating" for us could be translated "lethal" for the fish.

On the appointed day, February 21, we needn't have worried. Someone at Fabio Baudrit supplied the lethal factor. I don't know if everyone came to work drunk that morning, or what, but they packed all 400 fish in one small bag—with a little water. To compound the problem they placed the bag in a box with no support to hold its shape, so that sharp corners were formed, into which the panicky fish crowded and died of asphyxiation.

Seeing the still lively "sardines" at the airport, I supposed myself to be in the presence of some new advance in fish transport technique, shaped up the bag with some coconut shells, and loaded them on the truck. By the time we reached Puerto Viejo, it was clear that emergency measures would have to be taken.

The first step was to open the bag, stir the water and get out those fish which were already dead. This attracted the attention of various of the village elders, who had been sitting around waiting for an event. I was soon swamped with contradictory advice based on their accumulated store of wisdom and experience.

I managed to borrow a few plastic pails and began changing water with little regard for the conventional practice of equalizing water temperatures. Several bystanders were pressed into bucket brigade service. As my eyes were necessarily focused downward, on the fish, I became accustomed to addressing feet as they appeared. So I was somewhat surprised when I did look up and saw a rotund, florid San José business man (I suppose) in white shirt and tie wondering why he had been so peremptorily ordered to get a bucket of water.

We loaded several pails of fresh water into the canoe and continued on down the coast, exchanging water all the time--not all that easy a thing to do in a canoe at sea. To add to our woes, the day was hot and the sky clear—a little overcast might have helped. All in all, I think we did well to release 60 more or less live tilapia into the pond.

But that was not enough, and the whole process, including the 16 mile hike to arrange the shipment by phone, had to be repeated on March 8. This time, thanks to the direct intervention of Sr. Nanne, the fish were shipped right. Despite rough seas, we made it to the ponds with only three losses out of 400 fish.

Meanwhile, we were experiencing two other problems. The most perplexing was a water shortage, which has thus far prevented us from using the larger of our two ponds. Prior to constructing ponds we surveyed the older residents of the area as to the possibility of drought. There had never been one until 1977–78. The normal weather pattern is a "dry" season from January to May, then a "rainy" season, peaking in August and again in November and December. The rains came more or less on schedule in June, 1977, though the amount of rainfall was less than normal. But, for the first time in anyone's memory,

there was no significant rain in November and December. That, along with a more or less normal dry season, led to almost continual low water in the larger pond, which finally went dry in April.

By the time the fish arrived it was already apparent that the larger pond was in danger of drying up, so all the tilapia, regardless of sex, were placed in the reproduction pond. Eventually even that pond, which is quite a bit deeper than the growing pond, fell so low that we ceased feeding and constructed bamboo and coconut frond shades in the pond to retard evaporation and cool the water.

We were worried, not only that that pond might dry up too, and cause the loss of all the fish, but that the unprecedented weather might represent a long-term climatic change, such as has already afflicted the Pacific Coast of Central America. As it happens, the smaller pond did not go dry, and the rains have been more or less normal since May, 1978. But it will take a couple more normal years to completely convince us that the drought of 1977–78 was just a freak occurrence.

One good thing about being involved in any sort of farming venture—there are always enough immediate problems peculiar to the individual operation to save one from morbid preoccupation with long-term environmental problems. In the case of the NAISA fish culture project, while we watched our water evaporate we could ponder what had become of the nets we had ordered. Trying to do any sort of intelligent management of fish without nets, scales to weigh fish and food, etc., is sort of like trying to chop bush with a nail file in place of a machete. But that's where we found ourselves as of April, 1978.

I had delayed ordering our fish culture equipment while waiting for a grant proposal to make its tedious rounds. Finally, in November, 1977, I got up off NAISA's hard-earned nickels and ordered the nets, grant or no grant. This theoretically gave us time to receive our tools ahead of the arrival of the fish. The nets arrived several weeks after the fish.

The plan had been that New Alchemy would purchase the equipment and have it shipped to Catholic Relief Services (CRS) in New York, whence it would go by boat to Limón. Our friends at CRS in Costa Rica would help us get it out of customs without paying duty.

Weeks passed. No word of the nets. Some detective work by John Contier of CRS established that they had been loaded on a ship called *The American Legion* in New York. *The American Legion* does *not* go to Costa Rica. Perhaps they were transferred to another ship? Possibly. The CRS warehouse people in New York, the line which owns *The American Legion*, the shipping agents in Limón, and the customs people at the Port of Limón all pleaded utter inability to answer that question. For all we knew, our fish culture tools could be like Charlie on the MTA. They could have been doomed to shuttle back and forth between Spitsbergen and the Maldives until the oil finally runs out. (I might add that it is impossible to purchase small mesh nets in Costa Rica, so our problem was urgent.)

Finally, CRS in San José received a notice. Our nets would arrive February 10 in Limón. They did not. All hands once again pleaded total ignorance and inability to help us. More weeks passed. Another notice arrived. Somehow, our nets had gotten unloaded February 18 in Puntarenas. Not as bad as it could be—right country, wrong ocean.

Now, those of you without experience in this sort of thing might suppose that from that point things became simple. You reckon without the *aduana* (customs) and its capacity to make things difficult. I don't know what it is about customs people. There are some institutions which are merely confusing. With a reasonable command of the appropriate language and once you learn the ropes, what you thought was a morass of confusion and inefficiency becomes quite manageable. Not so the aduana. The aduana does not discriminate, on language or any other basis, nor can it be "managed." Aduana employees spare no effort of creativity, leave no informality uninvoked and miss no chance to invite you back tomorrow for another round. (I especially remember one episode when John Todd sent me some Otabs—tablets which release oxygen in water, to be used in shipping live fish. These were classified as "medicine," thus opening a whole new wonderland of regulations and forms.)

In the case of our nets, the aduana, perhaps inadvertently, outdid itself. Some behavioral deviate in the Puntarenas aduana actually tried to be helpful. This anonymous person sent the package on to San José—but forgot to send the requisite forms. The Puntarenas aduana was adamant that they couldn't release the forms unsigned and unstamped. And of course the San José people couldn't release the nets without them.

At this point a deep bow to Horacio Pestaña of CRS, who spent who knows how much time shuttling between San José and Puntarenas, and finally succeeded in extracting our equipment on April 9. Following another truck, boat and horse trip, the nets arrived in Gandoca on April 11.

The following day we netted our first sample, which disclosed that our fish were pleasingly plump and apparently growing well. I say "apparently" because, owing to the presence of our scale in the Puntarenas aduana, the initial weight of tilapia stocked had to remain unknown. The sampling also disclosed the greater difficulty of netting *Tilapia nilotica* than other species. Particularly in our soft bottomed ponds, they are adept at diving under the net. We have yet to solve this problem to our satisfaction.

In the course of sampling we were able to remove 18 pounds of "weed" fish, which could compete with the tilapia for food. They included *Poecilia sphenops*, the

"molly" of aquarists; *Hemieleotris fasciatus* (?) and *Eleotris amblyopsis,* two sleeper gobies; and *Astyanax fasciatus,* a characin. Some of these were eaten by our neighbors, but there was more interest in the three pounds of delicious fresh-water shrimp we hauled out. While the future of commercial fresh-water shrimp culture is doubtful, they are undeniably a fringe benefit of aquaculture in the lowland tropics, where they appear unbidden wherever there is water.

With regard to feeding our tilapia, this is really the crux of the project, or at least our claim to distinction. Those who have attended any of my Farm Saturday workshops or read some of my other writings are familiar with my views on commercial concentrates as feeds for cultured fish. Ecologically, economically or energetically based objections to commercial concentrates are all the less debatable in a developing country like Costa Rica or when the object of culture is a fish like tilapia which has been promoted chiefly on the basis of its low position on the food chain and suitability for low-cost production.

It must be admitted that many of the concentrates "work"—on tilapia as well as on obligate carnivores like trout and catfish. It is also only fair to point out that in Costa Rica great progress has been made in developing Costa Rican substitutes for imported concentrates which are ecologically benign and a great deal cheaper than the feeds imported from the U.S. But all discussion of concentrates is academic in Gandoca, where neither the economic means to purchase them nor the facilities to transport them exist.

The primary food of our tilapia is derived from the natural and augmented fertility of the ponds. The ponds are built in a swampy spot and, as in much of the lowland tropics, the natural fertility of such areas substantially exceeds that of surrounding high ground. A more surprising fact is that, while our agricultural soil is problematically acid, our pond water is near neutral in pH.

Whatever their chemistry, the ponds, prior to stocking, supported a luxuriant and diverse population of small fish, shrimp, insects, etc. Less appealing was a rank growth of filamentous algae. This had its merits as a mulch (we have even considered building a special shallow pool just for that purpose), but to a fish culturist it is an unmitigated detriment.

Just prior to the arrival of the first lot of fish, we began to fertilize the pond with horse and cattle manure in porous plastic bags. The ensuing bloom of phytoplankton, the primary food for the tilapia, quickly put an end to the filamentous algae—a "textbook" example of weed control by competition.

Apart from algae, the principal tilapia foods available to us are the plants we have planted for that purpose, principally melanga. We have much to learn about feed plants but at present we recommend malanga, for the following reasons:

1. easy to cultivate using traditional methods,
2. likes to grow near water,
3. pest-free (with the exception of our famous land crabs),
4. produces a starchy corn edible by humans and livestock,
5. produces a very large quantity of leafy material, and
6. easy to cut and feed.

For all the virtues of phytoplankton and malanga, there is still no substitute for a small amount of animal protein as a growth promoter, particularly in young fish. Our first batch of fish got off to a fast start, thanks to the abundance and diversity of small animals initially present. Presumably there will always be some production of young mollies, shrimp, insect larvae and zooplankton, but predation by a large population of tilapia will drive these sources down to a much lower level than was initially present.

Our first attempt to parallel our Cape Cod efforts with earthworm and midge larva culture and U-V bug-light insect traps, involved the scourge of local construction, the termites (locally known as *comejen* or "wood lice") which form large round nests wherever there is dead wood. The local people have long recognized their value as animal feed; it is a common practice to harvest nests to feed to chickens and they are also used as bait to trap shrimp. Our attempts at "culture" so far consist merely of cutting naturally established nests and setting them up on a suitable site. Most of these transplants "take"—new runs are formed and termites go on living in the nests. But the population density in our transplanted nests has not approached that in natural nests, thus reducing their utility. We would welcome suggestions from any termite experts.

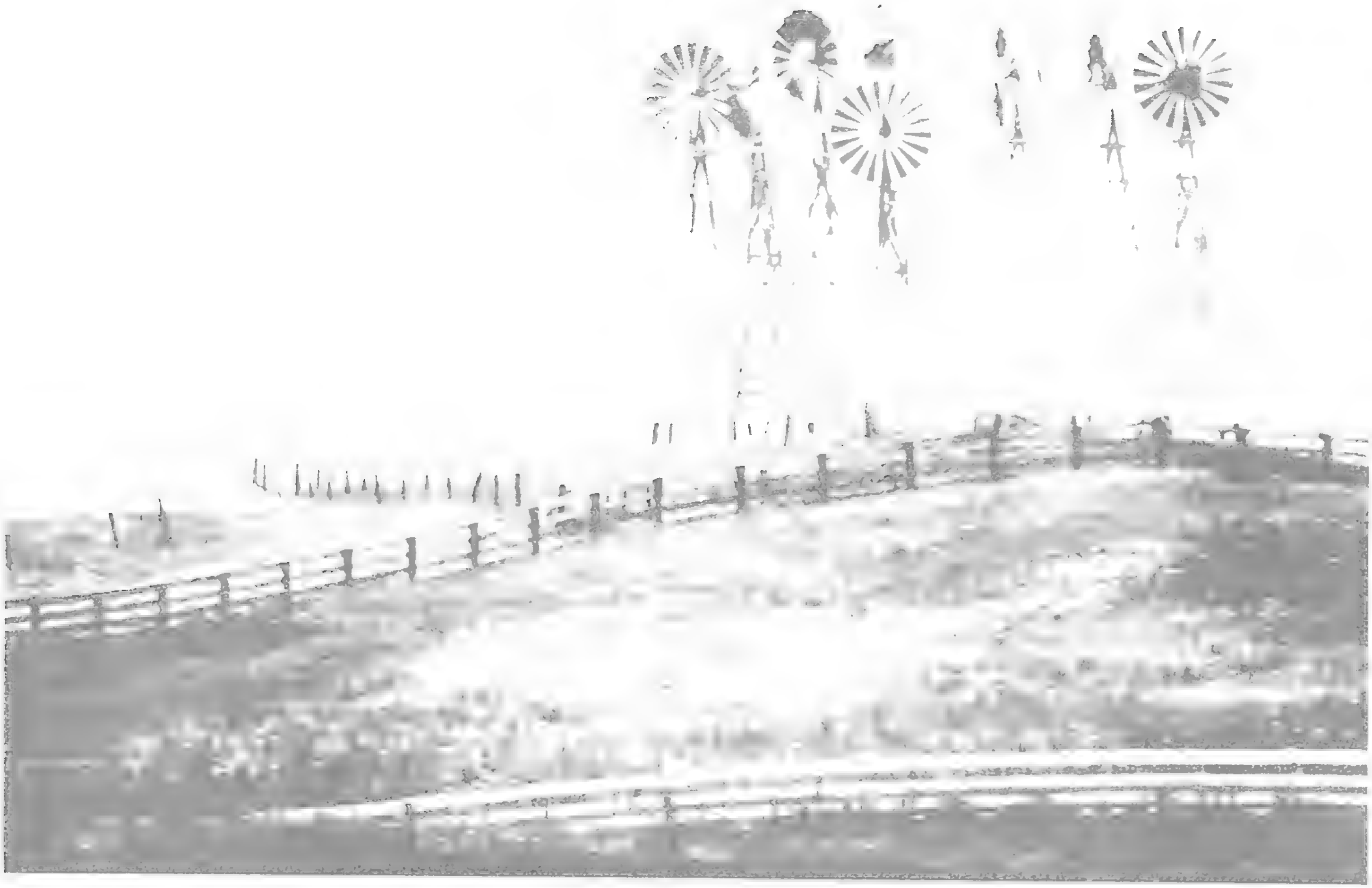
Further development of the termite work is a priority, as is the stocking of the large pond with all male tilapia and a few guapote (*Cichlasoma managuense* or *Cichlasoma dovii*), a large predatory cichlid used to control excess small fish. But our plans suffered a setback when Oscar left to seek work elsewhere. Until we can begin training someone to take his place, the tilapia will mark time in the ponds, and we will endeavor to learn Latin patience.


Energy

As the idea of massive, single-shot solutions to energy demands wanes with the increasing unavailability of inexpensive, accessible energy sources, the appeal and the rather satisfying logic of smaller scale, and specific end-use energy applications begins concomitantly to win acceptance. In his article, "An Integrated Wind-Powered System to Pump, Store and Deliver Heat and Cold," Joe Seale discusses first the theoretical aspects and potential pitfalls of such a system and then goes on to some of the practical potential applications. Joe's subsequent shorter article, "Whatever Happened to Compressed Air?" further illustrates from our own recent experiment that, as with the application of any technology still in its infancy, there is still considerable trial and, in this one specific case, error.

Gary Hirshberg's "A Water-Pumping Windmill Primer" is the continuation of a series of hands-on or how-to papers on water-pumping mills that we have published over the years. As both we and our mills become more experienced and durable, we feel very eager to pass on what we have learned. Gary has worked extensively with our own sailwing water-pumper, Big Red, and built a duplicate in Boston for the Boston Urban Gardening program. He has also traveled about visiting other windmill sites and windmill people and has taken courses in building windmills, so it is obvious that his writing springs pretty directly and recently from his own experience.

NJT



A Water-Pumping Windmill Primer

Gary Hirshberg

Most readers of *The Journal of the New Alchemists* do not need to be lectured on the merits of substituting wind power for conventional energy sources. To a believer, a windmill is more than an alternate energy device. It is a key to independence and self-sufficiency—an inspiration and a banner declaration of new attitudes. It's sexy and lots of fun.

Because most of us alternative-minded folks are already convinced, all we really need is to have our heads pointed in the right direction. As with any new technology, we need a theoretical understanding of the device, an economic perspective on the application, and, perhaps most important, a reasonable and current dose of product knowledge in the appropriate field(s). These foundations having been laid, the requisite information for installing and maintaining a wind system comes easily.

This article attempts to give you some of the foundation in each of these areas. I shall discuss the comparative advantages of water-pumping windmills and look briefly at their use through history. I shall examine the parts of a typical water-pumping windmill system and will discuss how to select a mill for a particular application. Finally, I'll share a few "tricks of the trade" as to erecting and maintaining a mill.

Wind-powered water pumping is dependable. A properly installed and maintained wind-powered pump can give over forty years of reliable service. Recently I dismantled an 1893 Corcoran mill that was still pumping after eighty-six years. A regreasing and the replacement of a few parts has it in shape again for at least another eighty.

Water pumping with wind is cheap, and needless to say, with escalating fuel costs, the relative savings will be increasing over time. In 1973, Prof. Stephen Unger of Columbia University published a note in the *New York Times* in which he analyzed the economics of electric pump vs. windmills. He found that a typical water-pumping windmill costs 50% less than a comparable electrical submersible pump over the lifespan

of the mill, which is rated conservatively at twenty years.[1]

As I hope this article will make clear, wind-powered water pumping is easy, requiring about the same skills it takes to perform home plumbing tasks, or to build a small shelter.

And finally, harnessing the wind for your energy needs is inspiring and joyful. The gentle, steady sweep of moving blades and the trickle of water from your well gives a sense of independence, responsibility, and an attunement with Gaia and her delicate richness. For most of us, the transition to a wind-powered water system can be simple and reassuring. For those not yet prepared to separate themselves from conventional power sources, or for those with marginal winds, a number of efficient and low-cost compromises are available.

WINDMILLS VS. WIND GENERATORS

For the windmill neophyte, let's first distinguish windmills from wind generators. Windmills are machines that capture the energy in the winds directly for such mechanical work as water pumping, grinding, compressing air, etc. Wind generation, which involves the transformation of wind energy to electricity can be efficient but is generally more expensive and obviously is more complex.

The current, near-exclusive focus on electrical generation cannot be taken as evidence of the superiority or even the necessity of electricity for all wind energy uses. The energy requirement for pumping water is less than that for electrical generation. Water pumpers are designed to operate in lower winds and at lower power levels than wind generators, and thus are able to operate in a wider range of locations. The lifting and transporting of water is an appropriate use of wind power because it is a direct mechanical application that requires moderate energy inputs. Energy storage is facilitated effectively and cheaply by storing water for windless periods.

A less obvious advantage of direct wind-powered water pumping deserves mention. Should a fire break out in a house or workplace, one of the first items to go is electrical wiring. If that is the power that you are relying on for water, to put it bluntly, your goose is cooked.

A BRIEF HISTORY OF THE WATER-PUMPING WINDMILL

The roots of wind-powered water pumping are noble indeed. The first recorded mills are from seventh-century Persia and were used for grain grinding and irrigation. The first account of windmills in Europe dates from 1105 when a French permit was issued for the construction of a water-pumping machine. A deed from Normandy contains the same report from 1180. The thirteenth century saw windmills gain widespread acceptance. In the fourteenth century, Dutch "scoop" or "tower" mills came into use for grinding corn and pumping water. It is known that there were at one time approximately 9,000 wind machines in Holland, a number so significant that in the early 1600's the Bishop of Holland claimed the wind as his own and imposed an annual duty on windmill owners. (Even the utilities have distinguished roots.) By the late nineteenth century, there were more than 30,000 mills operating in Denmark, Germany, Holland and England producing the equivalent (in mechanical power) of 1 billion kilowatt-hours (kwh) of electricity.[2]

The multibladed American windmill actually bears little relation to the European mills. During the period of the great western thrust of the railroad, steam locomotives needed dependable water supplies particularly in the remote, dry areas. With classic Yankee ingenuity, a man named Daniel Halliday invented the American multibladed mill in 1854. Unlike the inefficient Dutch scoop mill which was incapable of lifting water more than 16 feet, Halliday's mills could draw water from hundreds of feet below the surface. He sold thousands of these large diameter (25 foot) machines. In 1886, Thomas Perry came up with a model for an aerodynamic blade, a design that has not been improved upon even by the most sophisticated computer projections. Perry's model has been in use ever since. The period from 1880 to 1910 saw over 100 manufacturers in the windmill business. Between 1880 and 1900 the combined capital investment in the American windmill industry grew from less than $700,000 to $4.3 million.[3] Since almost all the machines were open-geared, the cowboys on large ranches were sent out each week with oil-filled saddle pouches, or with corked whiskey bottles filled with replacement grease, to keep stock-watering mills in good shape. Most cowboys detested these machines as they did all mechanical devices ("can't eat a windmill when things get rough").

In 1915, the Aermotor Company of Chicago patented the first self-oiling machine which simply enclosed the open gears under a water-resistant case. This early and decisive advantage catapulted Aermotor into being the most widely distributed machine in the history of the business, accounting for 70% of all sales in the 1920's. Windmills continued to boom until the early 1930's when rural electrification promised (deceptively) cheap power to every home and

[1] S. Unger, "Disappearing Windmills," Letters to the Editor, *New York Times*, January 3, 1973.

[2] Wilson Clark, 1975, *Energy For Survival*, Garden City, N.Y.: Anchor Books, p. 521.

[3] "Windmills in Foreign Countries." Special Consular Reports, Vol. 31, U.S. Department of Commerce and Labor (Washington, D.C.: Government Printing Office, 1904), p. 17.

farmstead. The electric-pump people must have followed closely behind the electric-line layers, for the windmill business dropped with a subsequent sudden crash. There are still a few hundred thousand mills standing out there, and a fraction of them are still pumping. Now, thanks to skyrocketing energy costs, Three Mile Island, and a general dissatisfaction with helpless dependency on the power grids, water pumpers are starting to sell again around the country and around the world.

THE WATER-PUMPING WINDMILL

Excluding the well and storage facilities, a current water-pumping windmill consists of most of the basic components shown in Figure 1. These are:

The Wheel or Rotor Assembly

The wheel is the part of the machine that catches the energy of the wind and converts it to rotary mechanical power which is available for work. Wheel diameter is a critical factor in determining the appropriate machine for your needs. The diameters of commercially available wheels range from 6 to 16 feet. In some cases 20 foot wheels are available. I shall discuss how to choose the correct diameter in the next section. The power of a wind machine is proportional to the square of the diameter of the blades. If the diameter of the blade is doubled, the power output is therefore quadrupled.

The overall power conversion efficiency of the large surface area water-pumper wheels is much lower than the sleek aerodynamic blades of a high-speed wind generator. Most water pumpers are designed to furl out of the wind at 35 rpm. Such wheels are designed to produce high torque at low wind speeds, however, and therefore are well suited to direct mechanical applications.

The Gear or Transmission

The wheel connects to the gear which converts rotary motion into vertical motion for pumping. Typical gear ratios are 4:1, that is four rotor turns for one pumping stroke. Most modern water pumpers have closed gearboxes and require only an annual oil change.

The Tail (optional)

Windmills can be either upwind or downwind machines. Upwind machines require a tail to keep the nose or wheel into the wind. The disadvantage lies in the cost of extra materials. The advantage of a tail is that it can be triggered by a spring connected to the gearbox to pull parallel to the wheel in high winds. This self-

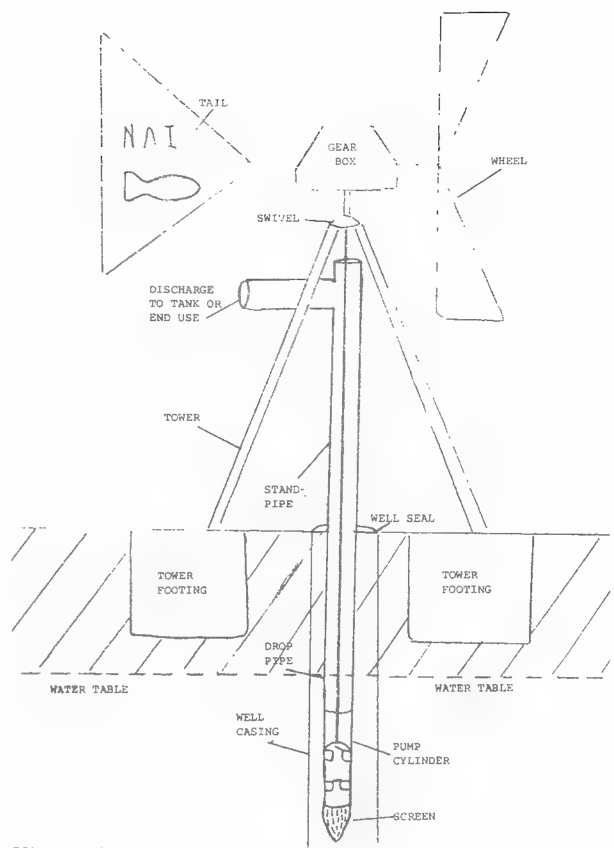


Figure 1.
The Components of a Water-Pumping Windmill.

furling mechanism, which can be adjusted by the spring tension, effectively shuts down the mill and prevents self-destruction in high winds. When the gusts subside, the tension on the spring releases, the tail opens out, and the wheel turns back into the wind. We chose a downwind design for our New Alchemy sailwing in spite of this asset, in an effort to develop the lowest-cost water-pumping solution. I don't know of another downwind water pumper on the market today.

The entire top assembly including the wheel, tail, and gearbox are mounted on a turntable or shaft which allows orientation or yaw with changing wind direction.

The Tower

The most important consideration for the tower is to get the wheel above nearby wind obstructions. As a general rule, the tower should be at least ten feet higher than any obstructions to wind flow within 100 yards of the mill. Commercial towers available from water pumper manufacturers range in size from 21 to 47 feet in height. For higher towers, wind generator catalogues should be consulted.

The tower must be absolutely plumb and the tower-

top platform level, or the lifetime of the machine will be drastically shortened. Needless to say, the tower must be strong enough to support the wheel mounted on it and to withstand the maximum anticipated wind stresses. Manufacturer's specifications are detailed and precise. Should you choose an alternate tower, look carefully at the stress specifications, and be very sure not to cut corners. Cost savings vanish when the machine has to be retrieved off the ground after a storm.

When building your own tower, use only high-quality bolts and hardware. On a well-built tower every bolt should be in tension. Bolts from an old tower may be fatigued and worn from tower stress and shouldn't be re-used. Consult an engineer or local concrete contractor on footing specifications. On Cape Cod, we use 3,500 pound compression concrete for towers under 35 feet tall.

As to choice of building materials: wood looks nice, but is functional only in dry climates like the Southwest. In locations with any moisture at all, it's better to go with steel. We've tried a number of wooden towers (see the fifth *Journal*), but I don't believe any of the designs will last longer than eight years. Preserving wood is an expensive and potentially poisonous way to add a few years to your tower. On the other hand, in the Southwest, I've seen redwood and other wooden towers that are still sturdy after 70 years. But here we have decided to go with steel. It's dependable and virtually maintenance free, and most steel towers will outlive you. A final hint about towers: hoisting the underground pipe assembly for repair and maintenance is much easier if the tower height is a few feet greater than the longest section of drop pipe and pump rod.

The Well Seal and Pump Rod Assembly

The submerged positive displacement pump or piston pumps are generally the cheapest and most versatile water movers. Above-ground pumps that suck water up are easier to install, but even the most efficient suction pump can create a negative pressure of only one atmosphere. Theoretically this means that at sea level you can raise a column of water 32 feet by suction, but, as it turns out, friction losses and temperature changes render a suction pump incapable of pulling more than 22–25 feet.

The linkage between the mill and the pump cylinder is called the pump rod. The pump rod begins with a shaft that extends from the gearbox, through a swivel. This swivel allows the upper rod to turn with the yaw of the machine without rotating the entire pump-rod assembly. This shaft connects to the red rod. Generally a wooden (ash is most common) 1″ x 1″ piece, the red rod is designed to be the weakest link, or fuse, in the system. If anything goes wrong above or below it, the red rod will usually break, minimizing damage to other more expensive or less accessible parts of the mill. The red rod extends downward and connects to the polished rod which passes through the packer head or standpipe and the well seal. The well seal is just that, a simple expandable cap designed to keep dirt, insects, small animals, and other detritus from falling into and contaminating the well and water supply. The polished rod is usually made of brass to reduce friction. Brass serves to reduce corrosion as well, which is important in a part that works in both air and water.

At the bottom of the pump-rod assembly is the sucker rod, which connects to the pump plunger or leathers. Shallow wells (less than 100 feet) will generally use cheaper, solid steel rods. One-hundred to 250 foot wells will use hollow "Airtite" rods for buoyancy, and those deeper than 250 feet make use of light, buoyant oak or ash rods.

The Drop Pipe or Pump Cylinder

Usually the well driller cases the well. This is a must in sandy terrain like Cape Cod. The drop pipe, which can be a good grade galvanized pipe of any size, is then lowered to the desired depth. The drop pipe screws into the pump cylinder at the bottom. At the top it is screwed into a tee or coupling which keeps it from dropping into the well. The drop pipe should be slightly larger than the cylinder to permit removal and replacement of the pump leathers without having to pull up the whole pipe. It is important that the drop pipe be smooth on the inside, otherwise, replacement leathers will be damaged when the plunger is lowered back into the cylinder.

You can purchase either open- or closed-top cylinders. The closed-top cylinder is less expensive but since the plunger and leathers can't be pulled out to release the water in the drop pipe, you will be forced to pull the entire weight of the water column to replace the pump leathers. This comes to about five pounds per foot of two-inch pipe and can only be used in shallow wells.

The plunger diameter and length of the plunger stroke are major factors in the windmill's pumping capacity. Standard cylinders range from 1⅞ to 4 inch diameters. It is best to stick with a 1⅞ inch cylinder if possible, to permit leather removal through a standard 2 inch drop pipe. Pipe costs can scale rapidly above 2 inch diameters. In my area, 2 inch is \$3.19/foot and 2½ inch is \$4.80/foot, a 50.5% increase. The stroke of the windmill is the distance that the plunger moves up and down. A short stroke enables the windmill to begin pumping in light breezes, but in stronger winds a long stroke allows for greater volumes of water to be pumped. Many gearboxes are designed to permit stroke adjustment.

It is usually wise to put a screen just below the

cylinder to prevent sediment from entering the cylinder and damaging the leathers.

The Packer Head or Standpipe

Once water is lifted, it is pushed through the drop pipe to the surface, and out through a tee or discharge pipe. Before discharge, water can either continue to be lifted into a standpipe (Figure 2), or can be diverted at a seal on top of the drop pipe known as a packer head. The standpipe is used when water is being delivered horizontally to storage. The height of the standpipe depends on the desired head or pressure needed to transport the water. When water is being delivered to an elevated storage tank, or when a seal is desired over the drop pipe to guard against contamination or vandalism, a packer head must be used. The packer head is an inexpensive fitting that seals the drop pipe and prevents overflow. Needless to say, in freezing conditions, the use of a standpipe would be foolish. The packer head would need to be protected in an insulated, underground housing.

TRANSPORT AND STORAGE OF WATER

Once water has been brought to the surface, what next? How do you get it to the desired end-use location, at the optimal pressure and necessary flow rate? This section will touch on the types of options in this phase.

Whether water has been lifted by suction, or by positive displacement, the best way to build up water pressure is to raise the water to a greater height than the place of end use. This can be done by pumping it to a tank either on a nearby hill or elevated on a tower. Every foot of elevation gives you about .43 pounds of pressure per square inch (psi). In other words, it takes 2.3 feet to get one psi. Most household applications require 18 psi, or about 41.5 feet of head.

The easiest way to pump water into a raised tank is to extend the drop pipe to a height greater than that of the top of the tank. The upper limit of a standpipe is the height of the pump-rod swivel, or the top of the tower. The disadvantages of this system are that it eliminates the fuse or red rod, and in addition it limits transport to pathways below the height of the standpipe.

If elevation is a problem and you don't want the hassle of constructing a tank, you can always use the simple and proven scheme of moving water to an on-the-ground holding tank that is coupled to a pressure tank through a small electrical centrifugal pump. In this way, the windmill still performs the major work of bringing water to ground level, and electricity is needed only for the relatively minor job of building up pressure. The larger the pressure tank, the less often the centrifugal pump will have to operate. The pressure tank should be close to the house to save on the amount

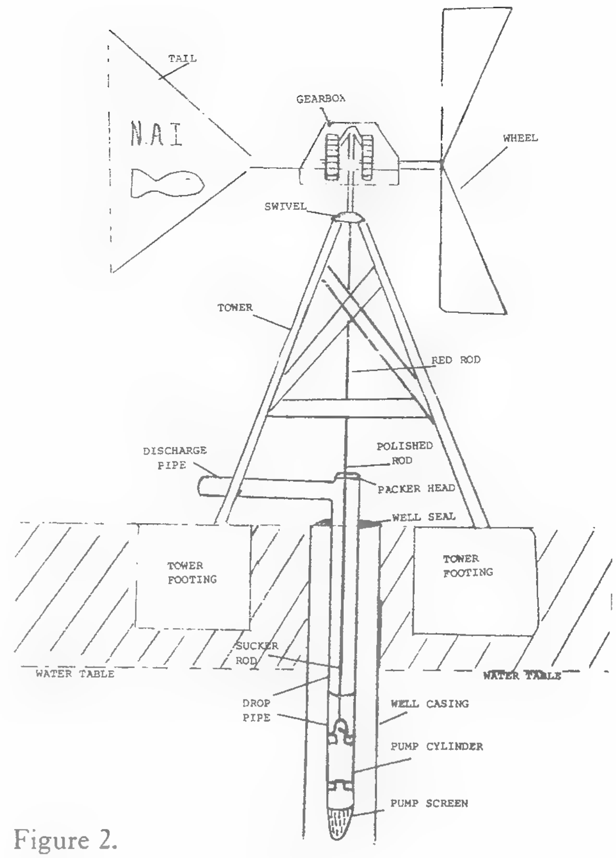


Figure 2.

A Water-Pumping Windmill with Standpipe.

of larger-diameter pipe required to handle the pressure tank outflow.

Pipe frictions must be considered when choosing the proper size plumbing for water transport. This is a matter of assuring that the psi is still adequate after friction losses in transport. Consult a standard schedule 40 steel-pipe friction chart or talk to your local plumbing supplier to avoid this simple but potentially costly error.

Elevating a storage tank is not as awesome a task as it might seem. A 5,000-gallon tank can be rolled up a moderately sloped hill by several people. You can pull a tank on to the tops of driven posts with block and tackle, and then build a platform underneath. Another simple scheme involves gradually building up the tank from underneath with alternating railroad ties.

The simple rule of thumb in tank selection seems to be in accounting for worst case demand. You can assume a daily rural per capita need of 50 gallons. In the Southwest, windmill people consider a ten-day stored supply safe. You'll wish you'd planned for excess storage capacity if a fire should break out. You should always plan for enough head to wet down your roof.

SELECTING THE MILL

Decisions about the proper mill are based on three basic considerations:

1. How deep is the water (of how much life is required)?
2. How much volume is needed?
3. How fast does the mill have to pump?

Wells and well technology are beyond the scope of this article. There are a number of do-it-yourself techniques for building wells. The VITA manuals are excellent guides for such schemes.[4] Depending on circumstances, you can drill, drive, or dig your own well. It is sometimes best to hire this job out. Professional well drillers can get the job done in a short time. The driller should tell you the drawdown or the rate at which the water is replenished at different depths. This is more critical in high-speed, high-volume electrical pumps, but it is useful information if you are coupling a submersible pump with your windmill.

Once you have your well, you need to determine the depth to water, and to add ten feet for pump submergence. Then calculate how high you need to lift the water to obtain the necessary end-use pressure. The distance from pump depth to the upper height is the total elevation (see Figure 3). Again, the required lift can be calculated by determining desired end-use pressure and multiplying by 2.3 to get the minimum necessary storage height. With the answer to this question you have your necessary head.

The required water volume can be computed by consulting plumbers, farmers, or neighbors. Plan for water use beyond per capita needs, as coverage against fires, etc. Finally, calculate the worst case rate demand, remembering that storage can help save on this item.

When you have these three figures, you are ready to pick the windmill best suited to your circumstances. I shall discuss four models currently available: the New Alchemy Sailwings, the Aermotor, the Baker, and the Dempster. Two other water pumpers are available commercially: they are the Bowjon, a low-volume air-lift pump, and the Sparco, a small (58 pounds) low-volume machine. As of this writing, I have had no personal experience with the latter two mills, and am unable to comment on their performance. Addresses are included at the end of this article, however.

New Alchemy has designed, developed and demonstrated two successful, low-cost, water-pumping windmills. Our sailwing windmills (see the fifth *Journal*) were developed to meet the need for a low-cost, reliable pump that could be constructed using local skills and readily available materials. One mill is currently operating a low-lift (5 foot), high-volume aquaculture pump on Cape Cod and the other, implemented jointly with the Arca Foundation and the Zen

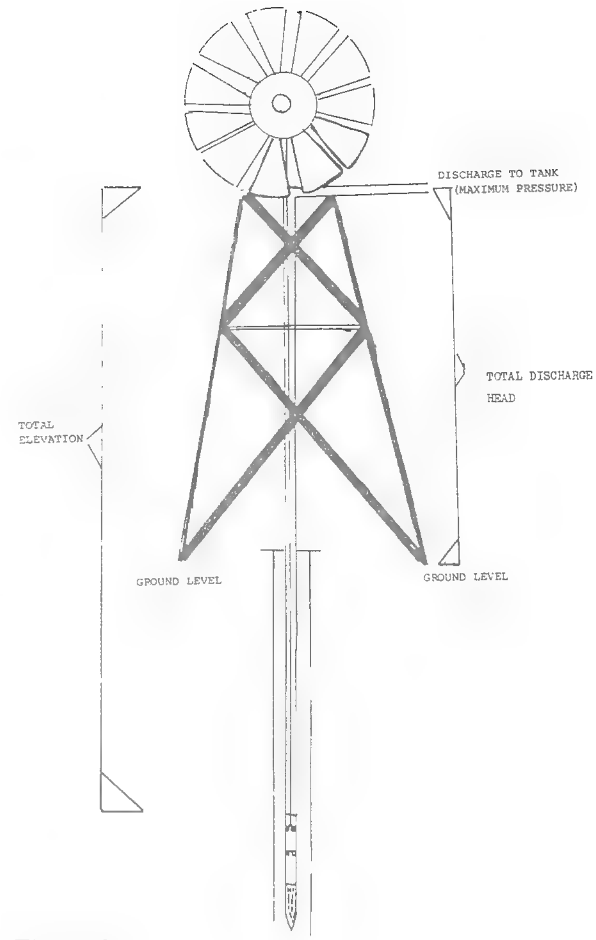


Figure 3.
Total Elevation and Total Discharge Head of a Water-Pumping Windmill.

Center, is irrigating a farm valley in California with a high-lift (130 foot), double-acting piston pump. Both mills cost under $1,000 to construct with pumps. This figure could drop proportionally with resourcefulness.

The sailwings are proven, reliable machines. There are several vital considerations in choosing whether to employ this design, however. The mills are not available commercially, although the plans are yours for the asking, and the mill thus yours for the building. A second consideration is that, unlike commercial water pumpers, the sailwing does not have an automatic furling mechanism for high winds but must be hand-furled to prevent damage in winds over 40 mph, which means that it is less capable of operating independently. If you want to cut costs and build your own machine, are willing to tend it and to remain nearby, I recommend the sailwing highly. Aesthetically, it has everything else beaten cold.

On the other hand, the convenience of "off-the-shelf" windmills and replacement parts may be worth the extra costs. Baker, Dempster and Aermotor are the only active, commercial, metal multibladed water pump-

[4] See in particular: *The Village Technology Handbook*, 1970 by VITA, 3706 Rhode Island Avenue, Mt. Rainier, MD 20822.

ers on the market today. Each is proven and reliable with long anticipated lifespans.

Aermotor is by far the largest manufacturer and accounted for 80–90% of all windmill sales in the late 1920's. They have since moved their factory to Argentina, and it is no secret in the industry that the quality has been reduced in the move. They are currently known to be cracking down on deficiencies, and do offer materials and workmanship guarantees for one year. Baker mills, which are manufactured by Heller-Aller, are less costly than Aermotor and have excellent sales and service people and also offer a one-year guarantee. Dempster too makes an excellent machine, and offers a limited five-year parts and construction warranty.

Each of these companies provides elaborate and detailed literature on how to select the correct model and size for your needs. Figure 4 is a typical chart of pumping capacities in a 15 mph wind. It shows that by mixing and matching various windmill and cylinder sizes you can come up with a combination that best meets your needs. It is important to note that this and similar charts are based on the long stroke of the windmill. This is done in order that the respective manufacturers will look their best on paper. An adjustment to a shorter stroke will result in a reduced pumping capacity, but the mill will start up in lower winds. Since few of us ever see 15 mph *average* winds, it is better to choose from the chart on the basis of short-stroke measurements if they are available. Aermotor's pump chart, for instance, indicates that a change from the long to short stroke will increase your elevation by one third and will reduce your pumping capacity by one fourth.

The best rule is to pick the largest wheel and the smallest cylinder for your situation. This not only allows for start-up in low winds, but minimizes the mechanical strain on the system as well. Yet another critical consideration is that if winds are 12 mph on the average, the mill's capacity is reduced by 20%, and in 10 mph average winds, the capacity is reduced by approximately 38%. It is essential that you know your winds.

Needless to say, tower height comes into play in this figure and you should select the tower accordingly. It is best to purchase the tower that is manufactured for your chosen windmill.

If, for example, you have a demand for 250 feet of head and 800–1,000 gallons of water per day, and if the wind averages 10 mph for five hours per day, you will have to choose a 12-foot mill with a 1⅞ inch cylinder. If the same site were subject to 12 mph winds for five hours per day, a 10-foot mill on a lighter-weight, less-expensive tower would be sufficient. This means a cost of about $1,000 less for the wind speed increase of 2 mph. Of course costs could also be cut $1,000 by halving water consumption, but the point is, to know your winds, and to think hard about your water use.

Joe Carter, of *Wind Power Digest,* calculated that according to local pump dealers, a typical submersible pump for this application would cost about $900 in 1979. Operating costs would amount to about 2 kw for one hour per day at $.05 kwh, or $36.50 per year. If you add in the lifespan of the pump which, on the average, is six years, with a replacement cost of 40–50% vs. a 20-year conservatively estimated windmill lifespan, after 20 years you will have replaced three submersibles, costing about $1,215. Taken together over 20 years with a 7% electricity price inflation you have $132 per year in the twentieth year for the submersible compared to $20 to $80 per year for the windmill, depending on maintenance costs. This crude analysis supports Unger's findings.

One final note on selecting the mill: Don't discount a windmill just because your well is not at a great wind site, or for that matter in a place (like under your cellar) where it would be hard to locate a tower. Windmills can be fairly versatile and in some cases can be offset many feet from the actual water source (Figure 5). There are simple techniques for combining a submersible electric pump with a windmill. You can use a gasoline or electric-powered pump jack for emergency back-up pumping power. A large mill and a small mill, or booster mill, can be employed in tandem to give added capacity for transporting water over large distances. Windmills have broader application than most people realize.

Figure 4. *A Typical Chart of Windmill Pumping Capacity*

	Wind Rotor Diameter									
Cyl.	*6 ft.*		*8 ft.*		*10 ft*		*12 ft.*		*14 ft.*	
Size	*Elev.*	*GPH**	*E*	*GPH*	*E*	*GPH*	*E*	*GPH*	*E*	*GPH*
1⅞	120	115	172	173	256	140	388	180	580	159
2	95	130	135	195	210	159	304	206	455	176
2¼	75	165	107	248	165	202	240	260	360	222
2½	62	206	89	304	137	248	200	322	300	276
2¾	54	248	77	370	119	300	173	390	260	334
3	45	294	65	440	102	357	147	463	220	396
3¼	39	346	55	565	86	418	125	544	187	465
3½	34	400	48	600	75	487	108	630	162	540
3¾	29	457	42	688	65	558	94	724	142	620
4	26	522	37	780	57	635	83	822	124	706

* Gallons Per Hour

ERECTING YOUR WINDMILL

The best first step is to sit down and try to think through the entire process of erecting the mill. Good planning can save time, money and extra trips to town. The well should be built first, and the water tested right away. Then you can assemble the basic tools needed for the job. These include lots of heavy rope, some pulleys and chain, hammers, wrenches, vice grips, drift punches, screwdrivers, shovels (maybe a crowbar), pipe wrenches and pipe dope (affection-

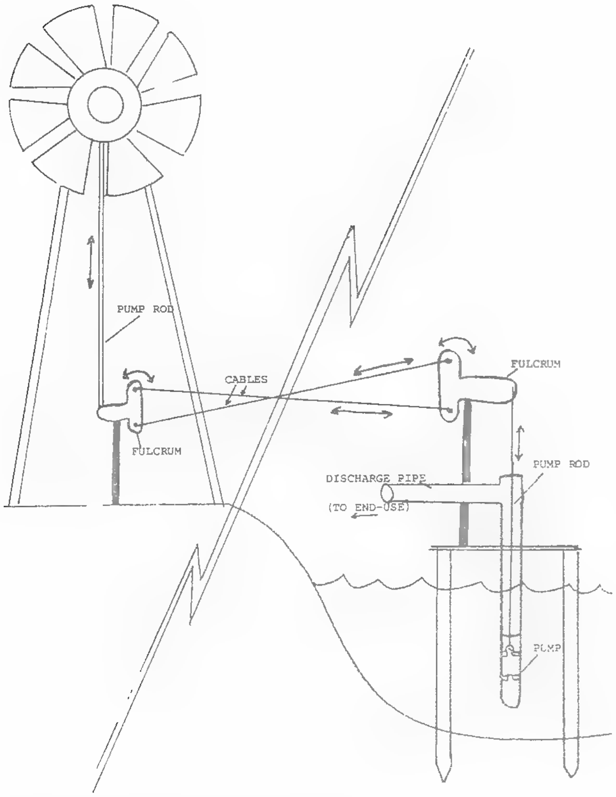


Figure 5.
A Water-Pumping Windmill with an Offset Pump.

ately known as turkey shit at our plumbing supply shop), and a good tape measure. A transit will help for leveling the tower although a long level can do the trick.

Once the well has been cased, the fun of putting in the cylinder and drop pipe begins. Invite a few friends. This is definitely not a one-person job.

You can either build your tower now or else build a temporary platform for raising your drop pipe sections vertically before they go down the well. We'll get back to tower construction shortly.

For the moment, first connect the cylinder and screen *(never, never, never* put a wrench directly on the cylinder—grab the coupling) and screw in the bottom section of drop pipe. Apply pipe dope liberally to the threads; it pays over the long run.

Lowering the drop pipe is both exhilarating and nerve-racking. It takes a lot of patience. If you are unfortunate enough to drop a section down the well, you are sidetracked into an auxiliary excursion into fishing for it which, at this juncture, is no fun at all. Tie your tools to your belt, and keep all possible contaminants away from your well casing. One easy way to lower pipe is with an angled bite with a pair of pipe wrenches. You can also use a pipe holder, or a pipe clevis. These hints take on added significance with each added pound of pipe that you lower into the well.

Attach each pipe section with great care so you don't have to pull it all back up again. Once you've reached the desired depth, fasten on a tee and rest the whole assembly on the lip of the casing. A typical installation will have at least one pipe section below the water table as insurance against drawdown. If you are coupling a submersible into the system, then be sure to have the well people calculate drawdown for different depths.

At this point, you can choose either a standpipe or a packer head. Right now I'll assume you are choosing the more common, latter strategy. The next step is seating your bottom check valve and connecting up your pump rod.

Seating your bottom check is as simple as dropping it down the drop pipe (literally) as long as you do it right side up. Make sure the threaded side is up and the valve is clear of cotton or paper ball protectors. The threads are useful when leather replacement becomes necessary, as we'll discuss in the last section. Drop the plunger down the pipe, and listen for the thud. Now attach the upper check to the successive pump rod sections and lower away continuing to add until you are near the top of the well. Slide the packer head over the rod and tighten it on to the drop pipe.

Now you are ready to erect the tower.

Directions for raising the tower are well explained in the manufacturer's specifications. The key is to be certain that the surface over the well casing is level. The slightest angle will damage the pump rod, and definitely affect the mill's performance.

Most tower footings are about four feet deep. One construction method is to build the tower piece by piece, to level and plumb, and then to pour the concrete. Another is to build the tower on its side and gin pole it erect and into place. I recommend the first method as it is easier to square up the tower. Lifting the rig is generally a more hazardous and expensive operation, requiring a truck, tractor, or crane.

The goal, in either case, is to get the tower vertical and into its holes. Shim it to level and pour the concrete. Give the footings a day to set and you are ready to lift the machine. Again, you can use a crane, or heavy machine if one is available, but it isn't necessary for the average water pumper.

If you are a bit more adventurous (or poor), get a sturdy piece of three-inch pipe and chain it firmly so that you have about six or eight feet above the tower top. Block it at an angle so that the pipe end is directly over the tower center, but the pipe will not obstruct the machine as it is lowered into the top fittings. Attach the block and tackle or pulley and thread through the lift rope before you stand the pipe up, or you are liable to be shinnying up some time later. The manufacturer's directions should take over from here. Grease the gears, and pull the machine up. A guide rope is useful to help keep the machine away from the tower during the ascent. One person topside should be able to guide the

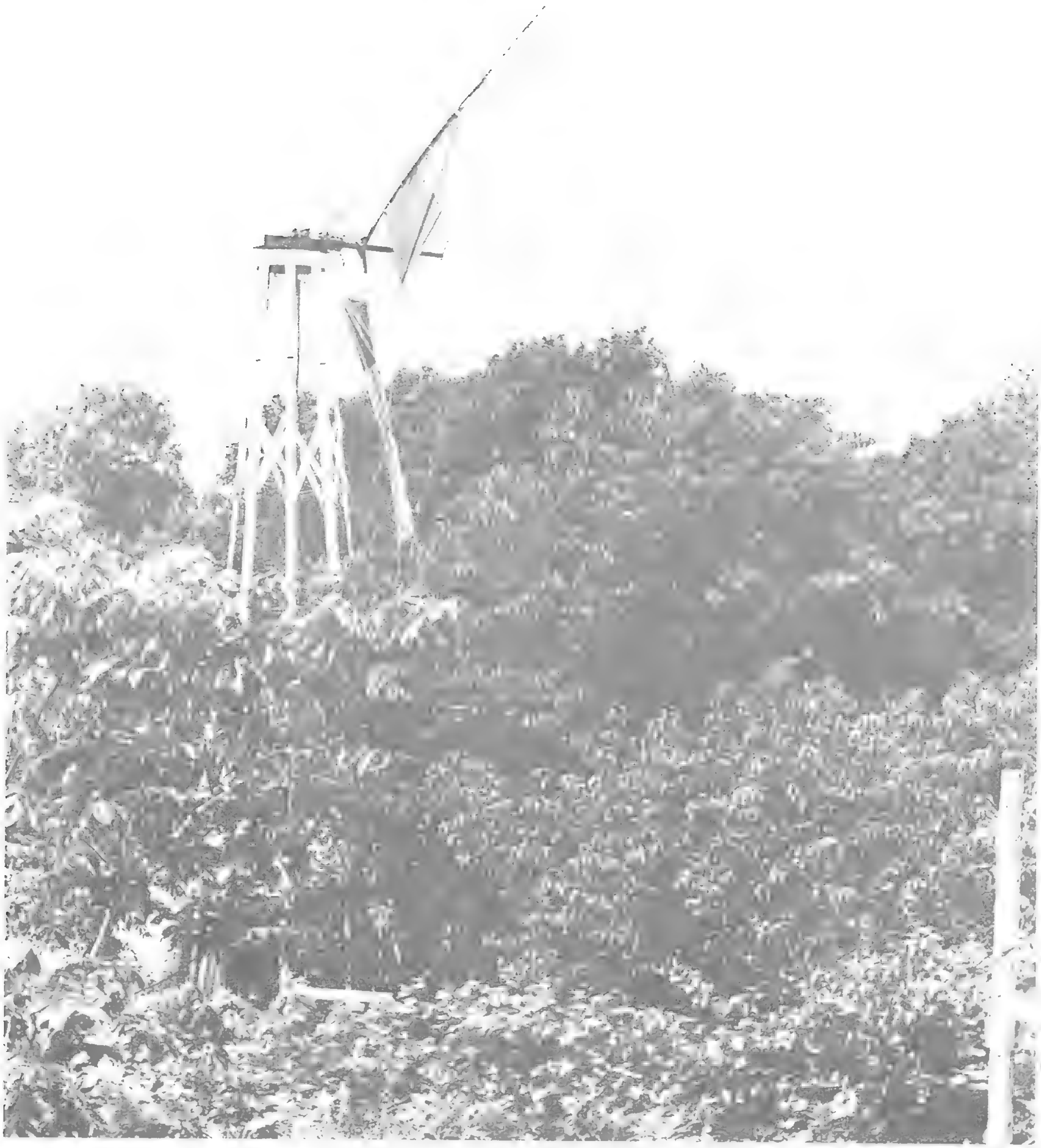


Photo by Hilde Maingay

machine into its supports. Now you can fill the crankcase with oil and attach the brake, tail, and furling mechanism. Assemble the wheel with care and attention to the order of each part. The sail parts should be weighed if they are not marked accordingly, to assure a balanced rotor. Line up the parts carefully to avoid wobble later on. Tighten it down slowly, rotating the wheel around a few times until it's been tightened evenly and firmly.

To connect the machine to the pump rod, turn the wheel to the *bottom* of the pump stroke, furl it out of the wind, and attach the pump rod and swivel. While sizing up the red rod for proper length, make sure that the pump rod is blocked at least two inches higher, so that the top cylinder leathers will not touch the bottom plunger. Cut the sucker rod and through bolt it in. It is best to give the wheel a few manual turns to guarantee a smooth and unobstructed stroke. With a little luck, water should be soon forthcoming. Hook up the lines and you are set to go.

MAINTENANCE

As for an annual maintenance check, a few tricks will suffice. Always use *SAE 7 weight non-detergent oil* for gear lubrication. A thicker oil will gum up and spill out, and will also allow metal fragments to float about in suspension, rather than sinking harmlessly to the bottom of the case. When changing the oil during the annual tune-up, a magnetic drain plug can be useful for picking up fragments. Clean the pan with kerosene, drain and refill with fresh oil. Check bearings and gears, and if one of a pair is broken, replace both. This insures against uneven stress and wear over the machine's lifetime. The annual tune-up should include a complete tower retightening.

When and if you ever need to replace the leathers, simply let the upper check down into the lower check threads, twist, and pull out. Be careful not to bend the pump rod and remember, disassemble as each coupling emerges from the well. Always coat new leathers with vaseline or a similar nontoxic lubricant. Give the new leathers a chance to soak and swell, and again, give the mill a few turns before unfurling, as a quality control check.

Once operational, it is still a good idea to familiarize yourself thoroughly with the manufacturer's charts and parts lists, or in the case of the sailwing, to reread old *Journal* articles. Two excellent sources of information can be found in a series on water pumping by Joe Carter of the *Wind Power Digest* staff (issues 14, 15, 16—1979), and in an excellent booklet put out by the New Mexico Energy Institute in Las Cruces. The author of this booklet, called *Selecting Water Pumping Windmills*, is a gruff but charming fellow named M. I. "Ras" Rasmussen. Ras teaches a top notch, two-weeks, hands-on course on water pumping windmills twice each year at New Mexico State University, which is a must for anyone who's contemplating a future in this business. It is a first-class learning experience taught by a true master, and is the only course of its kind any where in the world.

A few other useful addresses are included to help you on the road to water self-sufficiency.

Good Luck!

USEFUL ADDRESSES

Aermotor
Division of Valley Industries
P.O. Box 1364
Conway, Arkansas 72032

Baker
The Heller-Aller Company
Perry and Oakwood Streets
Napoleon, Ohio 43545

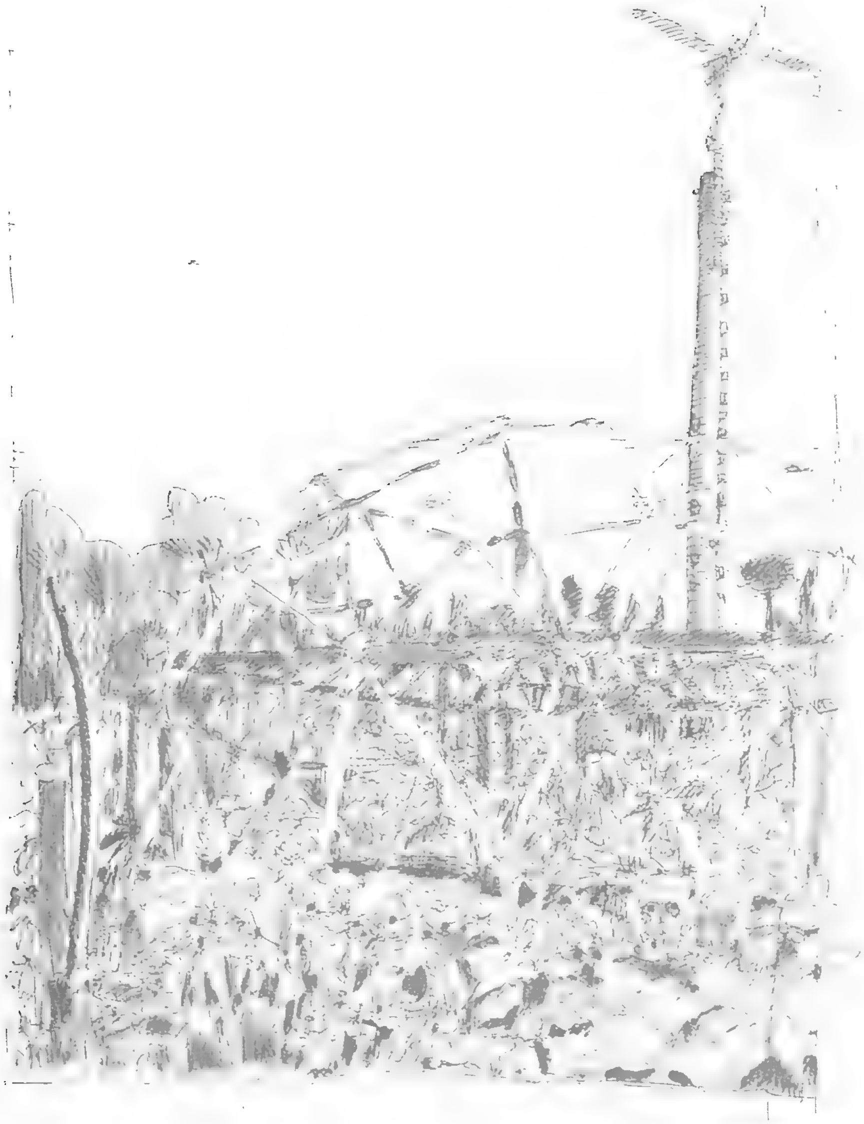
Bowjon
The Bowjon Company
2829 Burton Avenue
Burbank, California 91504

Dempster
Dempster Industries Inc.
P.O. Box 848
Beatrice, Nebraska 68310

SPARCO
Distributed by Enertech
P.O. Box 420
Norwich, Vermont 05055

Wind Access Catalogue
Wind Power Digest
54468 CR 31
Bristol, Indiana 46507

Windmill Course
New Mexico State University
Agricultural and Extension Education
P.O. Box 3501
Las Cruces, New Mexico 88003



Drawing by Jorge Bueno

An Integrated Wind-Powered System to Pump, Store, and Deliver Heat and Cold

Joseph Seale

Energy comes in many forms. Atmospheric wind energy is kinetic energy, the energy of mass in motion. The best-known way to harvest this energy and channel it to human use is with sails or airfoils such as we see on sailing ships, glider planes, and windmill rotors. Sails and airfoils transform the kinetic energy of the wind into mechanical energy, or work, which is force exerted through a distance, or equivalently twisting force (torque) exerted through an angular distance. For example, mechanical work pumps water by exerting force on a piston through the distance of many strokes, or mechanical work grinds grain by exerting torque on a millstone through the angular distance of many revolutions. These two examples are traditional windmill tasks.

In 1978, starting from first principles of physics and economics, I set out to identify and describe a practical, wind-powered system that might fulfill a widespread human need and to determine to which uses windmill energy is best adapted. The solution stems in part from the starting form of energy, which is mechanical, and depends on where wind energy is obtained which is usually on the top of a tower, and also on the distance of the windmill tower from a location of end use. The solution further depends on the variable availability of wind energy over time and consequently on whether a task can be performed at irregular intervals, as, for example, pumping and milling, so that the result of the task such as pumped water or flour can be stored, or whether the energy of the mill instead must be stored

in order to perform the task on demand.

This paper documents the outcome of my search: a heat/refrigeration pump and thermal storage system. The one that follows documents a dead-end attempt at an air compression heat/refrigeration pump and mechanical energy storage/recovery system that eventually evolved into the current concept. Started afresh, this same kind of search could probably lead to entirely different viable systems and many other dead ends as well. Much of the message of this paper concerns not the particular system but the process of breaking with traditional assumptions, as will be necessary time and again in many contexts in order to build a sustainable economy based on renewable resources.

If the concepts described in this paper continue to prove successful (a big "if," knowing how easily small matters can trip up the best thought-out plans at any stage of development), we hope they will lead to several years of applied research, design, and development, culminating finally in designs mature enough for manufacture and widespread practical use. The reader is warned against believing that the seemingly simplest concepts are simple in execution. There are many ways to build systems that work poorly, briefly, or not at all, and comparatively few ways to build systems that pay for the trouble, materials, and energy of construction. Fortunately, those "comparatively few" ways are still an infinite number.

THE PATH SUGGESTED BY THERMODYNAMICS

Energy production and energy use have become increasingly specialized and separate. And yet from the perspective of whole systems, effectively integrated energy systems require attention to the detailed nature of both energy resources and end uses. The recent abundance of energy has created no historical demand for such attention. Our maladaptive habits linger on so that concern for energy in our society is still overly abstract and quantitative at a time when effective energy strategy demands attention to particular and qualitatively different tasks. In the case of wind energy, the current near-exclusive focus on electricity generation cannot be taken as evidence of the superiority of electricity for all wind-energy uses.

Electricity is an energy form that is easy to control, transmit, and convert to many other forms. Thermodynamically, electricity is a zero-entropy energy form, which, by definition, means that its unavailability to do work is zero. In principle, electricity can be entirely converted to mechanical work. As the thermodynamic definition suggests, mechanical energy, or work, is the fundamental standard against which physicists measure the quality of all other forms of energy.

Since the energy delivered directly by a windmill rotor is mechanical work, one question arises. Might that form of energy be used directly to perform some task of major economic significance rather than being converted to electricity? The answer is emphatically yes. In the United States, fully 35% of delivered energy (strictly, enthalpy, which is gross energy without regard to quality of the end-use form) takes the form of heat to warm things and cold to cool things to temperature differences from the surrounding environment of less than 100°C. (180°F. differential).[1] The most energetically efficient known method to move heat across such small temperature differentials is by mechanical heat pumps.[2] Because of its high thermodynamic quality, one unit of mechanical energy driving a heat pump can move several units of low-quality thermal energy, the actual quantity increasing as temperature differential goes down. Depending on conditions, one unit of mechanical energy can move two to four units of thermal energy, resulting in an equivalent refrigeration of two to four thermal units, or a refrigeration coefficient of performance (C.O.P.) of two to four. The resulting heating on the other side of the heat pump is one unit greater, three to five thermal energy units, since the energy that drives the heat pump appears as extra heat output. (Note that usage of the term "heat pump" here includes both refrigeration and heating applications. Some authors apply the term only to heating end-uses while calling the same device a refrigeration unit when cooling is the end-use.)

THREE PRACTICAL HURDLES

While windmill rotor power is ideally suited to heat pumping on theoretical grounds, there remain three major practical questions to be answered.

Transmission

The first question concerns transmission. Can heating and refrigeration be delivered to where they are needed in a direct and efficient manner? For short to medium range applications (up to a few hundred meters or a kilometer, depending mostly on scale), the answer is yes. Any vapor-cycle refrigerant can serve as a medium to carry heat from the place where it evaporates and to deposit heat where it recondenses. Heat pipes utilize

[1] Amory Lovins, *Soft Energy Paths: Toward A Durable Peace* (1977, Friends of the Earth, Inc. and Ballinger Publishing Co.) pp. 80, 81. Figures for other countries run even higher. 37% for France, 39% for Canada; 50% for West Germany; 55% for United Kingdom.

[2] See *Heat Pump Technology*, June 1978, prepared for the U.S. Dept. of Energy, pp. ii-v. The result is given for electrical heat pumps, whose efficiencies are lower than for mechanical heat pumps because of minimum 10% (3-phase) or 15% (single-phase electrical-to-mechanical conversion losses (ibid., p. 48). The study shows that in terms of primary energy, i.e. fuel burned at the electrical power plant, electric heat pumps are not big fuel savers or money savers. Electricity generation, distribution, and conversion losses totaling 70% eliminate the major advantages of the final mechanical heat-pumping step. Fortunately, none of these losses apply to direct windmill-driven heat pumps.

evaporation, vapor transport, condensation, and capillary or gravitational liquid return to transport heat efficiently in this way. A vapor-cycle heat pump is essentially a heat pipe in which vapor flow is boosted mechanically to cause heat to flow "uphill" against a temperature differential. Insulated pipelines carrying refrigerant gases are a practical means of hot and cold delivery over moderate distances. The mechanical work that moves the gases can take place in a tower-top compressor linked directly or through gears to a windmill rotor shaft, and pipelines deliver the end products (hot and cold) to chosen destinations.[3]

Storage

The second question is, can heat and cold be stored at a practical cost for use in periods of insufficient wind? For many thermal end-use applications, thermal storage is much cheaper and simpler than any indirect energy storage, such as electricity-related storage. This applies particularly to the storage of cold, which is accomplished through the fusion of ice or inexpensive solutions with lower freezing points, as required.[4] Practical storage-time increases with scale since large objects have lower surface-area to volume ratios, hence inherently longer thermal retention, than smaller objects. With a reasonable thickness of good insulating foam, seasonal thermal storage becomes practical on a moderate scale. For applications where uninterrupted operation must be insured, significant investment in long-term storage is justified. The alternatives are either to invest in a much larger windmill rotor (easily five to ten times the swept-area may be required for a system with two weeks' storage as opposed to ten weeks' storage) to utilize light summer winds to meet maximum thermal load demands, or to invest in a motor-driven back-up compressor. In contrast to refrigeration, space heating demands tend to be much better correlated with strong winds, so heat storage can be smaller. In addition, back-up heating systems are much cheaper than back-up refrigeration components.

Rotor Load Matching

The third question is more subtle. Can a windmill rotor operate efficiently driving a heat pump, since the available torque from the rotor and the optimum rotation speed vary constantly with windspeed? Unmodified, a compressor will exert a torque that is almost independent of rotation speed. The optimum back-torque for a windmill rotor should remain quite low up to moderate rotation speeds and then increase steeply with further speed increases. Statistical modeling of performance of rotor/compressor combinations has shown that for economical rotor types the rotor efficiency loss is greater than 40%, even assuming the simple "fix" of an automatic clutch to permit rotor start-up without load.[5]

The most effective solution to this problem is a special modification to the operation of a refrigerant compressor to provide a low starting load and steeply increasing high-speed torque. Electronically switched electromagnets control the closure of the intake valves of the compressor cylinders, causing the pistons to compress on some but not necessarily all strokes. At low speeds, no compression takes place, so shaft torque is low. As speed increases, compression begins to take place infrequently, then more and more frequently until, at maximum speed and torque, every stroke is a compression stroke. A flywheel smooths the jitter in torque when the pistons are alternating between compression and no-compression strokes. The electronic circuit is simple and operates entirely from the power of timing pulses from a magneto turning with the compressor shaft.

ECONOMIC PROSPECTS

No wind-power system has combined the three features of refrigerant gas thermal transmission, thermal storage, and compressor matching to windmill rotor characteristics, into a working, self-contained energy system. To our knowledge, no wind-power system has used even one of these features. We believe that the total system described will be cheaper than any similarly advanced, total wind-electrical energy delivery system with comparable energy capability plus storage and/or back-up. Because of the additional advantages of high mechanical-to-thermal energy gain and end-usability of the system output, the proposed system should be directly competitive with existing utility-based thermal systems.[6] And for its price, the

[3] In case of a compressor on a horizontal axis windmill tower-head assembly that orients with changing wind direction, a two-way rotary pneumatic union is needed to connect gas flow to stationary down-pipes while allowing the compressor to turn with the mill. Such devices are manufactured commercially.

[4] Short-term cold thermal storage at freezing and subfreezing temperatures is commonplace in the food shipping industry. For an example of seasonal thermal energy storage we need only recall the unrefrigerated ice houses that once "powered" ice boxes in the northern United States throughout the summer.

[5] Computations by the author. Rockwell International, the contract monitor for the Small Wind Energy Conversion Systems (SWECS) program at the Rocky Flats plants, sponsored by the U.S. Department of Energy, is conducting a computer based study of statistical performance in variable wind regimes of nonoptimum compromise matches of rotors and loads. The author originally undertook this study to evaluate alternative approaches to wind-powered heat pumps.

[6] See footnote 2, particularly the 70% net losses from gross primary energy to electricity delivered to the heat pump. Lovins (op.cit., p.88) shows that capital "losses" to electricity transmission, distribution, and T & D system maintenance are about as severe as the total energy conversion loses of electricity production and delivery. Only about 29% of residential electric bills in the U.S. and 55% of commercial electric bills, pays for electricity. The remainder pays for delivery to the customer. We find in this a strong argument for the long-range diseconomy of wind-powered systems that rely on utility system energy back-up. The marginal costs to a utility in equipment and extra capacity are high since the demand of such users comes all at once, at the end of a long calm spell. See J. Seale, "Sun,Wind and the Power Company," *CoEvolutionQuarterly*, Winter 1978/79, pp. 30-31.

proposed system, in varying embodiments, will perform such diverse tasks as space heating; accelerated drying of lumber, tobacco, raisins, etc.; air conditioning; food refrigeration and freezing; and ice manufacture.

A FIRST EXPERIMENTAL EMBODIMENT

Limited technological, financial, and the human resources available at New Alchemy argue for a modest beginning. We intend to concentrate initially on exploring the novel aspects of the proposed system in an easy-to-manage, small-scale demonstration using one of our windmills and an air compressor modified to match the characteristics of the windmill. The compressor will be placed near the rotor and coupled via insulated pipes to freezer and to aquaculture tanks that are to be heated. Both are at ground level. Insulation will be placed in hermetic sections of coaxial pipe and the insulating space will be filled with a heavy gas that affords better insulation than air. The freezer itself will hold approximately two cubic meters (70 cubic ft.), about one-third of which will be filled with containers of salt brine for subfreezing thermal storage. Insulation thickness will be abut 30 cm. (one ft.).

The food-freezing component will be useful for seasonal crops and for the fish grown by New Alchemists, complementing on-going work and providing a demonstration of some of the major potential applications of the system. Winter heating of aquaculture breeding tanks by the heat pump will encourage survival and reproduction for fish sensitive to cold temperatures. Heat that leaks from the breeding tanks will help buffer the climate in the Ark and should enhance productivity in cold periods.

MARKET AND COMMERCIALIZATION RESEARCH

In the early stages we intend to direct a modest amount of effort to exploring markets for embodiments of the thermal system concept with commercial potential. We plan to spend comparatively little money at this stage relative to what could be spent on a "rigorous" analysis. Rigor is illusory when it comes to projecting what investors will pay for technologies that are not at the mercy of OPEC politics. More philosophically, what an "analysis" says that people will pay for renewable alternatives should not be the sole determinant as to whether those alternatives become available. Those who believe that human choice should guide economics need to take on faith that people will invest in well-designed equipment that accomplishes needed functions at an affordable cost in such a way as benefits the future as well as the next five years.[7] Such faith is scientifically unverifiaole, being part of a larger irreducible synthesizing force called human will.

The task of market and commercialization research therefore will be to identify directions that are practical, useful, and affordable, and to facilitate choices among the most promising directions. The kind of research apparent in the descriptions in the next section should illustrate the kind of analysis to be extended in the future.

TENTATIVE FUTURE SYSTEM CONFIGURATIONS

There are two opposing constraints on the choice of the embodiment of a system for initial development. The commercial immaturity of large windmill rotors implies excessive lead times to develop a large-scale system. Conservatism on initial investments in a new area also favors smaller systems. On the other hand, both commercial and engineering constraints, like the short thermal-storage times practical in small systems, as mentioned above, dictate that the system not be too small. Listed here are the embodiments of four systems in order of increasing minimum scale. For the first and second, storage time is the scale-constraining factor. For the third and fourth, commercialization constraints dominate.

1. *Dairy milk refrigeration combined with cattle wash-water heating.* Ice thermal storage, bio-gas back-up. Sale of surplus gas. Option to use heat pump to achieve pasteurization temperature before chill.

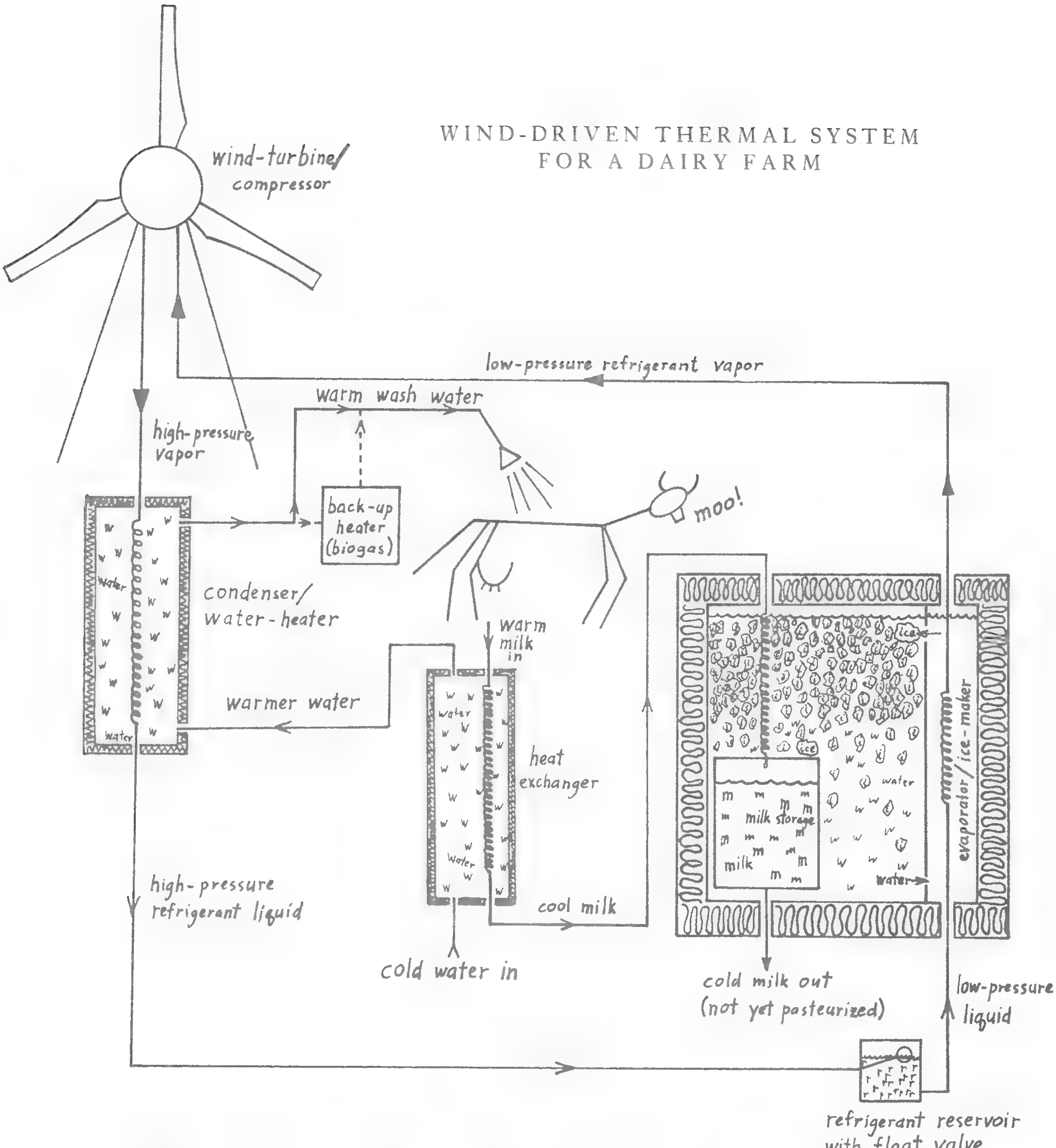
In New England an average dairy herd has approximately 60 cows, each producing an average of 15 kg. of milk per day.[8] Specifications for a system capable of handling such a herd in 4 meters/second (9 miles per hour) annual average winds, and a reduced herd of 50 cows in 3.6 m./s. (8 mph) winds, demand a 10 m. (35 ft.) diameter rotor with a mechanical power capacity of 1,500 watts to the heat pump. For milk cooling combined with wash water heat to 35°C. (95°F.), a cooling coefficient of performance (C.O.P.) of three is currently achieved, along with a simultaneous heating C.O.P. of four.[9] These figures are used for the above specifications. Thermal storage consists of 55 metric tons of icewater contained in a 4 m. x 4 m. x 4m. (13 ft.

[7] We do not abandon our earlier contention that the best embodiments of the proposed system will be economically superior to competing technologies in the near-term, if whole-system economics is the criterion. But whole-system economics is unfortunately not always market economics. Thus, we appeal to a higher wisdom that must recognize unwise subsidies and simple avarice, and work in the context of these realities to achieve sensible and humane economic goals.

[8] Dr. Stanley Gaunt, U.S. Agricultural Extension Service, Amherst, Mass.; personal communication.

[9] Dr. Louis A. Liljedahl, U.S. Dept. of Agriculture, wind energy specialist; personal communication. Dr. Stanley Gaunt (footnote 8) also reports the rapidly growing use of heat pumps for this application.

WIND-DRIVEN THERMAL SYSTEM FOR A DAIRY FARM



Principle: transfer heat from cattle wash water in two steps, first passive exchange, then by wind-powered refrigerant pumping. Use long-term ice cold storage, bio-gas heat back-up.

Notes: refrigerant lines are insulated. It would save energy to use wind-powered heat pump to pasteurize milk before chilling. The system shown is consistent with common farm practice to leave pasteurizing to a central milk distributor.

on a side) water tank (inside dimensions) with internal heat exchanger and milk tank. Insulation is 30 cm. (one ft.) thick urethane or other foam. Effective storage time at full use load is 90 days, sufficient for eight-to-one variation between the best and worst month average seasonal wind power fluctuation.[10]

With a counter-flow heat exchanger and warm-water storage tank it should be possible to exchange heat passively from incoming warm milk to incoming cold water, further reducing the work of the heat pump necessary to achieve final temperatures, especially in winter when the incoming water is cold. This combined with thermal storage could help improve year-round efficiency by a substantial factor so that the same windmill could service much larger herds, or so that a much smaller windmill would do the same job.

2. *Rural community locker plants for freezer space rental in possible conjunction with commercial food processing and storage.* Thermal storage at –21°C. (–6°F.) by freezing a eutectic salt (NaCl) brine. Heat may be used for nearby space heating.

The windmill specifications are identical to case 1. Refrigeration C.O.P. estimate: two. Thermal storage is also analogous: 55 metric tons of salt brine for 90 days at full use load with a high outdoor average temperature of 30°C. (86°F.). Freezer interior dimensions are 4 m. (high) x 5 m. x 7 m., with bottom 1.5m. filled by a salt brine pool penetrated by refrigerator pipes and passive heat pipes. Insulation is 40 cm. (16 in.) thick foam. User air lock. Design use load: 70 visits/day, two-minute stay, bringing in 2 kg. of food every other trip (proportioned two parts meat to one part fish to two parts watery vegetables, all presumed to enter at outdoor temperature, e.g., fresh harvest or slaughter).

For case 1, conduction loss through 30 cm. foam is less than 10% of the total thermal load, which implies that the diary system could be scaled down easily.For case 2, conduction loss through 40 cm. foam is 60% of the total thermal load, so that scale reduction would demand more insulation to compensate for poorer (larger) surface/volume ratio.

3. *Ice making plants for the fishing industry.* It will be practical to design for higher windspeeds at seacoast sites, as contrasted with cases 1 and 2. Ice is preferable to refrigeration for fresh-fish preservation since layering of fish and ice permits very rapid equilibration of fish to near-freezing temperatures without danger of freezing. Although heat can be sold for space heating while allowing a refrigeration C.O.P. of three, heat could be rejected to ocean water at a much lower temperature, permitting a refrigeration C.O.P. of at least five.

To justify the investment in harbor space, dock, loading equipment, etc., to service large fishing boats, a minimum commercial-scale ice plant might need to produce 2,000 tons/year.[11] Although this implies almost ten times the annual output of systems 1 and 2, several factors combine to keep the necessary rotor size down. With the availability of good seacoast wind sites, a reasonable design minimum average windspeed is 5 m./s. (11 mph) instead of 3.6 m./s. (8 mph). With condenser rejection to ocean water, a refrigeration C.O.P. of five is assumed. And the safety margins necessary, say, for a food locker with valuable contents and high cost of a thaw, will not be necessary for an ice plant that might have to lose a small fraction of its regular customers to a non-wind-powered competitor in a year with below average winds.

With these considerations, rotor size comes to 15 m. (49 ft.) diameter with a rated mechanical power of 10,000 watts. Storage capacity will depend on seasonal demand fluctuations as well as seasonal wind variability.

4. *Kiln drying of lumber or tobacco.* (Similar systems would be applicable to food drying, but as of this writing the author lacks concrete experience of food drying requirements on which to base even a tentative system description.) Vapor condensation and thermal recycling for top efficiency. No thermal storage or back-up.

In this system, hot and cold side heat exchangers operate in tandem as an air dehumidifier: the cold coils condense water, then the hot coils boost the dried air to a higher temperature than that of the moist air originally entering. Drying takes place in an insulated enclosure and the cycle remains closed except for the input of wet materials and the removal of dry materials plus water.

We lack data with which to estimate scale or performance of a system like this. The author has witnessed huge expenditures on fuel oil to dry tobacco in Maritime Canada. The winds there are the best in North America, and are very good by the tobacco harvest time in the fall. The demands for home space heating escalate at about the time that tobacco drying is completed. A hybrid drying/home-heating system would probably be necessary for good utilization and payback. Summer, the period of no demand, is the period of least wind.

[10] See P. C. Putnam, *Power from the Wind* (Van Nostrand Reinhold Co., 1948), pp. 90-91, for an example of seasonal variability in New England. The assumption of eight-to-one variation is conservative (i.e., safe). The calculations make a safety allowance for a year with 25% less than average wind power for the site, also indicated by Putnum's data (same pages). Data is available to research these assumptions much more rigorously.

[11] James W. Mavor, Jr.,Woods Hole Oceanographic Instituion: personal communication.

GLOBAL PROSPECTS

The technology growing out of such a program should be relatively simple and economical, encouraging small businesses to produce diverse subsystems (windmills, thermal stores, drying ovens, cold-storage warehouses, solar-plus-wind heated greenhouses) in a competitive market. While the United States is probably best equipped to support the costs of the early portion of the system learning curve, the knowledge produced will require technology of a scale and simplicity that is accessible to nations with less capital and fewer specialized engineers and technicians available. Wind-driven heat pumps and thermal storage systems should come to represent a significant quantitative step to a world-wide renewably based technology.

Whatever Happened to Compressed Air?

Joseph Seale

Everybody said that compressed-air energy storage for wind power was a natural and that somebody ought to try it. So we did. The first setback was suggested by theory, but we thought that we could turn that into an asset. Then economics, engineering details, and the available, state-of-the-art equipment were lying in wait and ambushed us.

Theory first. When you compress a gas, the work performed to squeeze it adds energy, causing temperature to rise. The temperature increase causes a proportional rise in pressure, with a resultant increase in the work required to compress the gas. If the compressed gas cools off before being used to run an air motor for energy recovery, then the pressure will be lowered and the extra work required for compression will not be recoverable. For compression to 7 atmospheres (100 pounds per square inch) the ideal theoretical efficiency limit for one stage compression and decompression is only 57%. The remaining 43% of the energy goes to pump heat.

Fine. Why not combine heat pumping with a mechanical energy storage and recovery system? Use the heat from the compressor to warm aquaculture tanks, the cold air exhaust from the air motor to freeze food, and the stored mechanical energy to run the blower motor for the rock heat storage system in the Ark. It looked like a superb example of synergistic, multifunctional use of equipment. We were very excited.

Enter the real world, real air, and real machines. Air contains moisture. As air cools upon expansion through an efficient air motor, ice sublimes out and freezes up the motor. There is a way around the problem with an air drying device --but that is expensive. Judging from the performance figures on motors, air motor manufacturers have found a cheaper solution; which is to make the motor so inefficient that most of the energy in the compressed air generates heat to prevent freezing. The most efficient combination of compressor and air motor that we could find is 8% efficient mechanically, and that is with an efficient two-stage compressor that cools the partially compressed air to minimize overheating and consequent excess compression work. Since most of the energy that might have been recovered mechanically goes to overcome motor freezing, the system makes a very poor refrigerator. Mostly, the compressor motor systems that we could buy degrade high-quality mechanical energy to low-grade heat which is of some utility, but not worth the price.

We considered the costs of compressed-air energy storage costs. A little math and physics shows that for a given strength of material (e.g., steel) used to make a compressed air tank, the quantity of material required varies in proportion to the volume-times-pressure capacity of the reservoir. In other words, there is no scale advantage or disadvantage for cost of materials, which is the major cost of large tanks. The following table confirms theory in practical terms:

1977 Prices, Tanks Safe to 125 PSI

Volume, gal	*Cost, $*	*Weight, lbs*	*Cost/Volume, $/gal*
125	$ 338	296	$2.70
235	$ 504	500	$2.14
660	$1,523	1,225	$2.31
1,550	$3,146	3,200	$2.03
2,200	$3,893	2,200	$1.77

Our guess is that the largest tank uses a reduced quantity of higher strength, more expensive steel to achieve lighter weight at a slightly better cost.

Suppose we were to use the 235-gallon tanks, which are bigger than four 55-gallon oil drums, with the best-combination 8% efficient compressor/motor system, to deliver one horsepower to run the blower for the rock storage in the Ark. Assuming an operating pressure range from 125 psi down to 80 psi (you can't use up all the pressure and keep the blower powered sufficiently), one tank will last less than two minutes and it would cost $270 per minute storage capacity for tank capital alone. For comparison, lead-acid batteries of equivalent energy delivery capacity cost less than a tenth as much ($17 per horsepower minute, initial capital). It should be noted though that with room for

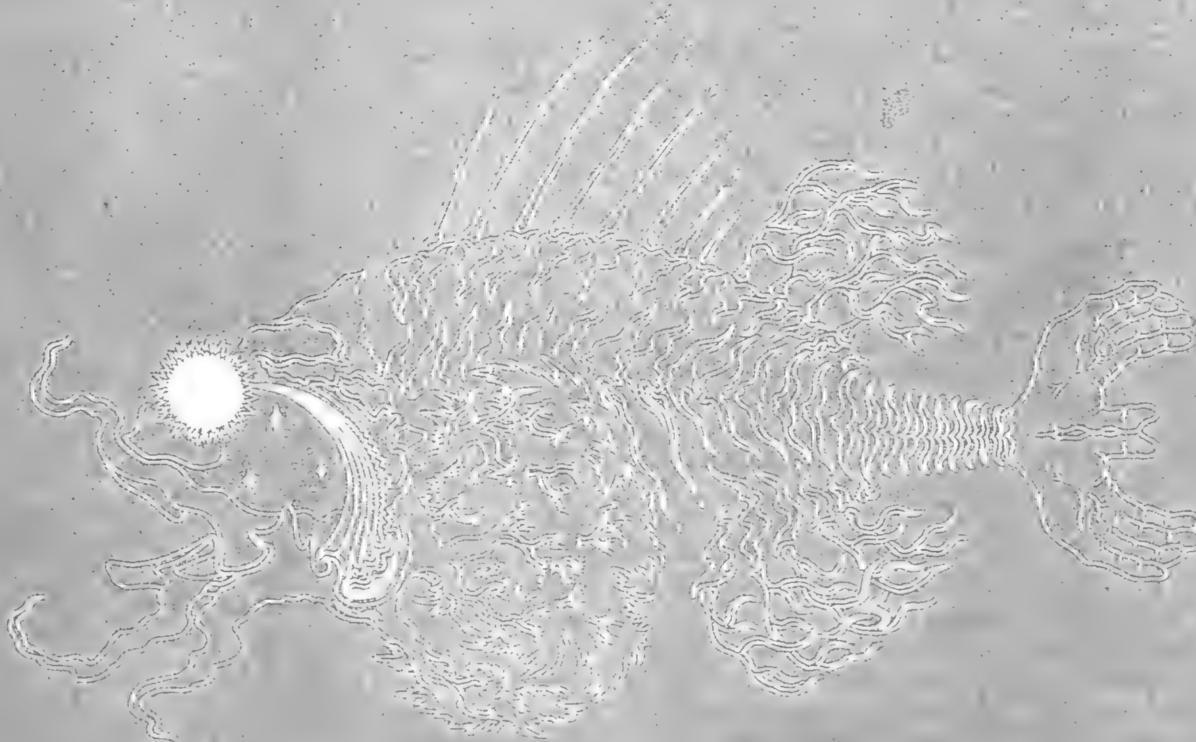
roughly tenfold improvement in air motor efficiency, and hence in effectiveness of use of air storage capacity, better equipment could change the whole economic picture.

What of future possibilities if we envision equipment not currently available? I have already indicated that the costs of the theoretical tank materials will vary roughly as pressure-times-volume capacity. The energy carrying capacity of a tank, assuming ideal recovery, is a somewhat more complicated function. The following table expresses theoretical energy carrying capacity divided by pressure-times-volume in order to indicate how performance/cost ratios might be expected to vary with design pressure:

Pressure, atmospheres (gauge)	1.00	3.00	5.00	7.00	9.00	11.00	13.00	15.00
Performance/Cost, arbitrary units	.28	.62	.84	1.00	1.13	1.24	1.34	1.42

Going up from the 7-atmospheres baseline case, we see a slight theoretical advantage in higher pressure, but the higher the pressure, the more difficult the thermal effects. Even when by-product heat pumping is taken into account, efficient high-pressure operation requires multiple stages of compression and decompression with inter-stage heat exchangers. (This applies to the 7-atmospheres range of current equipment.) This is the realm of complex industrial equipment, not simple wind machines.

Where geological reservoirs such as caverns, abandoned mines, or depleted natural-gas fields provide free storage, lower pressure operation with simpler equipment becomes feasible. There is a possibility that a compressed-air utility using pipelines, windmills, and natural storage might work. There was a municipal compressed-air utility early in this century in Paris. But at any practical pressure, thermal effects will be significant and will represent an efficiency loss wherever it is impractical to utilize the heat at points of energy production and the cold at points of consumption. Realistically, compressed-air storage for isolated small wind-energy systems seems out of the question.



Land and Its Use

Beyond supplying the vegetables and some of the fruit for all of us who work at New Alchemy, the gardens are one of the most beautiful places at the farm. And if that were not more than adequate, our gardens, over the years, have taught us a great deal about the relative merits of various methods and practices of raising food. Beginning quite literally from the ground up, our first task was to create a balanced fertile soil from the sandy terminal moraine that forms Cape Cod. Long before our soil had been tested and pronounced lacking in none of the essential nutrients as it has been recently, we had begun work with intensive vegetable production, biological pest control and the effects of such time-honored but not scientifically corroborated practices as mulching. For four seasons now, Susan Ervin has been engaged in a series of mulching experiments. In 1978, having eliminated as many variables as possible, she arrived at statistically significant and somewhat surprising data on the effects of seaweed mulch.

Although the garden and the bioshelters have been the centers of our agricultural work, Earle Barnhart's most recent project has started a considerable outward expansion. Earle has begun the extensive and longterm undertaking of establishing an arboretum of locally adapted fruit and nut trees, and trees to provide fodder for animals. The eventual goal, as he discusses in his article, is to create a mixed and sustaining, ecologically viable, agricultural landscape. Planting trees is satisfying not only in that it embodies an ecological ethic but because it is a gesture that, unlike so many others, invests in rather than robs the future. In his article "Three Crops," Earle explains some of the theory behind the ecological soundness of tree crops and goes on to describe some very workable designs.

NJT

Photo by R. D. Zweig

Further Experiments on the Effects of Mulches on Crop Yields and Soil Conditions

Susan Ervin

Over the past several summers we have been conducting experiments to test the effects of mulches on crop yields and on soil conditions. Our interest is in biodegradable mulches intended to enrich the soil as well as to control weeds, moderate soil temperatures, improve soil texture, and retain moisture. In one trial in the first phase of experimentation, unmulched lettuces yielded higher than either those mulched with seaweed or with those mulched with azolla, which is a small aquatic fern that grows on the surface of our fish ponds.[1] In a second trial, azolla-mulched sections yielded higher. In the second phase of the experimentation, the effects of seaweed mulch, leaf-mold mulch, and the absence of mulch were observed on tomatoes, sweet peppers, chard, lettuce and beets. Half of each crop received supplemental watering; half did not. Lettuce tended to be more productive without mulch. There was a clear trend toward higher yields for beets, chard, and tomatoes mulched with seaweed, though only chard showed a statistically significant higher yield. The significance of the other yield differences was masked by the fact that variation was due more to site than to treatment. Crops that benefitted from mulch had higher yields with seaweed than with leaf mold. Supplemental watering was not a significant factor in any of these cases.[2]

During the summer of 1978 we continued experimentation, attempting to obtain more conclusive results by limiting the number of variables. Because supplemental watering had not significantly affected yields

[1] Susan Ervin, 1977, "The Effects of Mulching with Seaweed and Azolla on Lettuce Productivity," *The Journal of The New Alchemists*, 4: 58–59.

[2] Ervin, 1979, "Effects of Mulches," *The Journal of The New Alchemists*, 5: 56–61.

the preceding year, we chose not to water any crop after a few initial waterings at the time of seeding or transplanting. The crops tested were tomatoes, beets, and lettuce. The mulch treatments were confined to two, seaweed mulch and no mulch. The lettuces were mulched soon after planting; mulch was applied to the other crops on June 24 and renewed on July 3. It settled to a covering of about 6″.

The lettuce variety used was Salad Bowl; the beets were Early Wonder, and the tomatoes were Rutgers. Planting and harvesting proceeded as follows:

Lettuce Trial I: Seedlings were set out June 7. Whole plants were harvested between July 10 and 18, with an equal number of plants harvested per section on each harvest day.

Lettuce Trial II: Seedlings set out July 21. Harvested between September 9 and 18, in the same manner as in Trial I.

Beets Trial I: Seeded June 1. Harvested August 2 and 3.

Beets Trial II: Seeded August 5. Harvested October 23.

Tomatoes: Seedlings set out June 9. Fruits were harvested when well ripened, beginning on August 8 and ending September 26, when the plants were damaged by frost.

Moisture and temperature data were collected using a Soiltest MC-300 meter. Sensors were placed 5″deep in two mulched sections (one and seven), and two unmulched ones (two and eight). Two sensors were placed in each of these sections to insure accurate data. The final figure recorded was midway between the readings of the two sensors. Variation between the two was slight at all sites. A stick thermometer was used to determine temperatures at a depth of 1″. Readings were taken in the mornings between 6:00 and 7:00 A.M., and in the afternoons between 4:00 and 4:30 P.M.

As expected, mulched plots were cooler on hot days and warmer on cold nights and showed less temperature variation overall. July 11 is a typical example: Morning readings of 69°F (20.6°C) and 70°F (21.1°C), afternoon readings of 71°F (21.7°C) and 72°F (22.2°C) for mulched sections at 5″; morning readings of 68°F (20°C), afternoon readings of 86°F (30°C) and 84°F (28.9°C) for both unmulched sections at 5″; morning readings of 61°F (16.1°C) and 63°F (17.2°C), afternoon readings of 70°F (20.6°C) for the mulched sections at 1″; morning readings of 58°F (144.4°C), afternoon readings of 88°F (31.1°C) and 92°F (33.3°C) for the unmulched sections at 1″. The mulched sections remained moister than unmulched sections throughout the summer, a fact of some significance in an area of quickly drying, sandy soil. Mulched sections also retained moisture longer after rain.

The following tables are excerpts from the data collected between June 26 and September 15. Complete data is available on request.

Moisture at 5″ Depth

	Mulched		*Unmulched*	
	1	*7*	*2*	*8*
June 26	.55	.52	1.60	1.90
July 10	.25	.22	1.70	2.70
July 24	.30	.60	1.55	1.95
August 7	.18	.28	.90	1.30
August 21	.67	.92	3.80	5.00
September 4	.71	1.20	9.80	25.00
September 11	1.00	1.30	14.00	30.00

Temperatures at 5″ Depth (degrees Fahrenheit)

		Mulched		*Unmulched*	
		1	*7*	*2*	*8*
June 26	A.M.	67°	68°	64°	64°
	P.M.	68°	69°	79°	76°
July 10	A.M.	68°	69°	68°	68°
	P.M.	71°	72°	82°	79°
July 24	A.M.	72°	73°	73°	72°
	P.M.	72°	75°	87°	81°
August 7	A.M.	70°	72°	72°	71°
	P.M.	71°	73°	80°	76°
August 21	A.M.	69°	70°	66°	67°
	P.M.	70°	71°	74°	72°
September 4	A.M.	64°	64°	58°	59°
	P.M.	65°	66°	72°	72°
September 11	A.M.	62°	61°	59°	59°
	P.M.	62°	61°	68°	68°

Temperatures at 1″ Depth (degrees Fahrenheit)

		Mulched		*Unmulched*	
		1	*7*	*2*	*8*
June 26	A.M.	58°	58°	58°	58°
	P.M.	68°	67°	77°	78°
July 10	A.M.	63°	63°	63°	63°
	P.M.	71°	72°	85°	86°
July 24	A.M.	66°	66°	64°	63°
	P.M.	71°	71°	87°	86°
August 7	A.M.	66°	66°	65°	65°
	P.M.	67°	71°	77°	74°
August 21	A.M.	62°	62°	60°	60°
	P.M.	67°	71°	77°	80°
September 4	A.M.	54°	54°	51°	51°
	P.M.	69°	69°	75°	74°
September 11	A.M.	54°	53°	52°	52°
	P.M.	63°	63°	70°	70°

Soil was tested to determine the effects of the mulch on soil fertility. The analysis of samples was done by the Cooperative Extension Service of the U.S. Department of Agriculture at Waltham, Massachusetts. Mulch-related variations were evident for nitrate, pH, potash, and soluble salt readings (Table 1).

TABLE 1—*Soil Analysis*

	Test Date					
pH	6/21	7/12	7/22	8/6	8/16	8/26
Section No. 1 (m)	6.6	6.1	6.4	6.3	6.4	6.8
2 (nm)	6.5	6.5	6.7	6.6	6.7	6.8
3 (m)	6.7	6.3	6.4	6.4	6.5	6.6
4 (nm)	6.8	6.6	6.7	6.8	6.7	7.0
5 (m)	6.9	6.2	6.5	6.4	6.7	6.6
6 (nm)	6.8	6.7	6.9	6.8	6.8	7.1
7 (m)	6.7	6.5	6.4	6.6	6.7	6.8
8 (nm)	6.8	6.6	6.8	6.8	6.5	7.1
Nitrate						
Section No. 1 (m)	H	EH	VH	EH	EH	EH
2 (nm)	VH	VH	L	H	M	M
3 (m)	EH	EH	VH	EH	VH	VH
4 (nm)	MH	EH	ML	VH	M	L
5 (m)	M	EH	VH	EH	EH	EH
6 (nm)	MH	EH	MH	EH	L	MH
7 (m)	MH	EH	VH	EH	EH	EH
8 (nm)	H	MH	M	EH	VH	MH
Potash						
Section No. 1 (m)	VH	VH	EH	EH	EH	EH
2 (nm)	L	VH	VH	VH	VH	L
3 (m)	MH	EH	EH	EH	EH	VH
4 (nm)	M	EH	VH	VH	VH	L
5 (m)	VH	EH	EH	EH	EH	VH
6 (nm)	M	VH	VH	VH	M	L
7 (m)	L	EH	EH	EH	EH	EH
8 (nm)	VH	VH	VH	VH	VH	M
Soluble Salts						
Section No. 1 (m)	15	NO READINGS	112	58	150	80
2 (nm)	20		15	20	28	21
3 (m)	23		80	110	180	122
4 (nm)	20		16	17	34	22
5 (m)	17		130	135	106	185
6 (nm)	14		22	17	22	23
7 (m)	11		250	96	222	98
8 (nm)	12		24	14	25	17

m = mulch
nm = no mulch
EH = Extra High
VH = Very High

H = High
MH = Medium High
M = Medium
ML = Medium Low

L = Low
VL = Very Low

It is known that potash penetrates more deeply in a mulched soil because of more uniform moisture distribution.[3] We had thought initially that during mulch decomposition there might be temporary nitrate shortages. This, however, did not prove to be true. Soluble salt levels, though much higher in mulched plots than in unmulched ones, did not reach levels generally considered to be damaging to most plants.

The yields are shown below (Table 2). The total yield from mulched sections in the first beet trial was 78.5% greater than from unmulched sections. The second trial produced yields 225% greater than in unmulched sections. The total yield of mulched tomatoes was 7.3% greater than unmulched ones, although some unmulched sections out-yielded some mulched sections. In the first lettuce trial the unmulched sections yielded 33.9% more than mulched ones, and 20% greater in the second trial though some unmulched sections were less productive than some mulched ones.

Using the t-test of significance between two sample means, the following resulted:

	t-value	*significance*
Beets I	5.48	99+%
Beets II	7.48	99+%
Tomatoes	.22	15+%
Lettuce I	2.20	92+%
Lettuce II	.78	52+%

In both trials, beets mulched with seaweed yielded significantly higher. In the first trial, unmulched lettuces yielded significantly higher. The differences between yields of mulched and unmulched plots for the second lettuce trial and for the tomatoes were not statistically significant.

Lettuce is known to have a low salt tolerance whereas that of beets is known to be high. Thus, the salt levels are most likely a major factor in resulting yields. Another

[3] George L. Slate, 1957, "How I Mulch My Garden," in *Handbook on Mulches* (Brooklyn Botanic Garden, New York).

TABLE 2—*Yields*

	Lettuce I		*Lettuce II*		*Beets I*		*Beets II*		*Tomatoes*	
Mulched Sections	*25 plants per plot*		*20 plants per plot*		*35 plants per plot*		*10 plants per plot*		*5 plants per plot*	
1	2,598 g	91.64 oz.	2,134 g	75.27 oz.	3,945 g	139.16 oz.	1,152 g	40.64 oz.	10,747 g	379.09 oz.
3	4,640 g	163.67 oz.	2,928 g	103.28 oz.	3,903 g	137.67 oz.	1,130 g	39.86 oz.	22,762 g	802.91 oz.
5	4,731 g	166.88 oz.	1,752 g	61.80 oz.	5,125 g	180.78 oz.	920 g	32.45 oz.	37,314 g	1316.21 oz.
7	4,359 g	153.78 oz.	1,044 g	36.83 oz.	4,497 g	158.63 oz.	1,314 g	46.35 oz.	12,884 g	454.47 oz.
Totals	16,328 g	575.95 oz.	7,858 g	277.18 oz.	17,470 g	616.24 oz.	4,516 g	159.30 oz.	83,707 g	2952.68 oz.
Average	163 g	5.76 oz.	98 g	3.46 oz.	125 g	4.40 oz.	113 g	3.98 oz.	4,185 g	147.63 oz.
Unmulched Sections										
2	5,010 g	176.72 oz.	2,604 g	91.85 oz.	1,910 g	67.37 oz.	380 g	13.40 oz.	14,702 g	518.60 oz.
4	6,451 g	227.55 oz.	2,660 g	93.83 oz.	2,426 g	85.57 oz.	410 g	14.46 oz.	25,100 g	885.38 oz.
6	4,745 g	167.38 oz.	1,398 g	49.31 oz.	2,835 g	100.00 oz.	152 g	5.36 oz.	19,667 g	693.73 oz.
8	5,667 g	199.90 oz.	2,780 g	98.06 oz.	2,641 g	93.16 oz.	446 g	15.73 oz.	18,579 g	655.36 oz.
Totals	21,873 g	771.55 oz.	9,442 g	333.06 oz.	9,812 g	346.11 oz.	1,388 g	48.96 oz.	78,048 g	2753.07 oz.
Average	219 g	7.72 oz.	118 g	4.16 oz.	70 g	2.47 oz.	35 g	1.22 oz.	3,902 g	137.65 oz.

observation that may or may not be valid is that in the second lettuce trial section 6 was the lowest yielding unmulched section and had low nitrate levels during part of the time of that trial.

The accumulated data from two years' experiments allow some interesting incidental observations to be made. Tomato yields were much lower this year using the same variety of tomato as used in the previous year. In 1977, the average production of seaweed-mulched plants was 9,132.06 grams; in 1978, 4,185.35 grams. For unmulched plants, the average 1977 yield was 8,054.63 grams; in 1978, 3,902.4 grams. Temperatures were lower during the 1978 season and moisture levels higher. In the next phase of our experimentation, we shall continue our work with seaweed, attempting to isolate its enriching effects on the soil from those that increase salinity. We will also begin to test the effects of mulching with straw, which is a material that is available more widely.

I should like to acknowledge the assistance of Nancy Jack Todd, Rebecca Todd, and Eleanor Labosky in carrying out this work, John Wolfe in the statistical evaluation, and of Al Doolittle in plotting graphs.

Photo by R. D. Zweig

Tree Crops: *Creating the Foundation of a Permanent Agriculture*

Earle Barnhart

Man's (sic) very existence is being threatened by his abysmal ignorance of what it takes to run a balanced ecosystem.

Eugene P. Odum
Fundamentals of Ecology

This paper is an exploration of the potential value of tree crops in agricultural ecosystems. The ecological dilemma of increasing population, rapid agricultural erosion and increasing energy cost is examined. A partial solution is presented which proposes tree crops as an ecological counter-strategy to these trends. Several designs are presented as examples of how tree crops may be used in rural, suburban and urban biotechnical landscaping. Lastly, promising avenues of tree-crop propagation research are suggested as necessary prerequisites to widespread adoption of improved agricultural trees.

Maintaining food production apace with population growth without irreplaceabley damaging the soil base on which productivity depends is a major dilemma in agriculture. While conventional agriculture can undeniably produce high yields, it cannot pretend to be sustainable in terms of either soil preservation or energy consumption (see References 1, 2, 3, 4 and 46). The following analysis explores current concepts of energy, ecology, and erosion in agricultural ecosystems and delineates the interdependence among land resources, energy resources and living communities. The goal is to indicate that high yields can be compatible with soil preservation and lower energy consumption if successful strategies drawn from natural ones are used as guides.

To feed 6–7 billion people by the year 2000, maintaining present demand use patterns, food production must be greatly increased (1). This increase can come from greater productivity on available lands or by farming more land. Doubling world food production on current land would require from 3 to 10 times the energy and resources of current agriculture (1, 6). Farming additional land implies using land of marginal quality, much of it hilly, which will require expensive maintenance to keep it productive agriculturally. The United States has already lost an estimated one-third of its topsoil and an estimated 10–15% of its former potential productivity, and the erosion rate is at a record high (4, 46). About $15 billion have been spent on conservation measures on the U.S. since the mid-1930's, yet each year $6.8 to $7.75 billion worth of nitrogen, phosphorus and potassium are still being lost, and $13 billion is spent repairing flood and sediment

damage to crops and pastures (1, 4). Presently 64% of the U.S. cropland needs treatment for soil erosion which is occurring at a rate many times higher than that considered compatible with permanent agriculture (1,3).

EROSION CONTROL OPTIONS

Any country with a serious desire to preserve its soil has several options. One path is technological, using mechanical force and humanly constructed structures to move soil and to restrain it from flowing downhill with water. Two examples of this approach are contour plowing (annually) or terracing (permanently). Contour plowing costs 5–7% more in time and in fuel but can reduce erosion up to 93% (1). Terraces are a noteworthy strategy since many of the longest-farmed regions on earth utilized them (26). Either method must deal with about 3-billion tons of sediment per year (1). The terrace solution is a relatively simple way to invest remaining fossil fuels in permanent fertility. It would be interesting to see an analysis of the cost efficiency of subsidizing permanent terraces with the money and energy now used for flood control and sediment damage repair.

A second option is erosion control by biological forces. The biological solution is attractive because of

the many beneficial by-products and because of its reliance on solar energy instead of fossil fuel to pay for the transition. The concept of using perennial plants, particularly trees, to produce human food and animal feeds while they protect the soil has been proposed by historians of agriculture like F. H. King (26), geographers of soil erosion like J. R. Smith (11), and economists to whom people matter like E. F. Schumacher (27). A landscape of perennials is the method nature has evolved for soil protection for most of the biogeographical regions of the earth that are now farmed (28, 29). Perennial plants tend to accumulate gradually such structures as roots, stems, twigs, detritus and topsoil humus. These parts of the plant normally shelter the soil from the direct force of the weather.

E. P. Odum, in *Fundamentals of Ecology*, estimates that if a natural ecosystem is to maintain its soil and to sustain a given level of productivity, more than half of its annual plant growth must be retained as structures that resist environmental stresses. If more than this fraction of annual plant growth is allowed to remain, the ecosystem gradually builds up biomass, becoming more productive and more resistant to forces of wind and water. On the other hand, if more than half of the annual plant growth is consistently removed (as in over-grazing or over-logging), an ecosystem gradually exhausts its structure and becomes less able to protect its soil, resulting in losses to erosion, and leaching, and in less productive capacity.

Only very small amounts of nutrients are lost from mature communities as compared to immature or disturbed ones, with losses decreasing along a scale from row crops to small grains to grasses to perennial forages to forests (3). Of particular interest are the management practices employed to bring erosion rates down to acceptable levels. Most of these involve various strategies to allow a more mature plant community to grow up intermittently and to produce soil-protecting "residues." Such residues carry over into the following few years, decomposing slowly until they are lost as protection. We can think of familiar practices including strip-cropping, crop rotation, manure application, and newer "no-till" cultivation as ways of averaging-in materials from perennial crops and organic matter similar to that accumulated by unharvested plants. All maintain organic structure near the soil surface that resists abrasion from rain, wind and water.

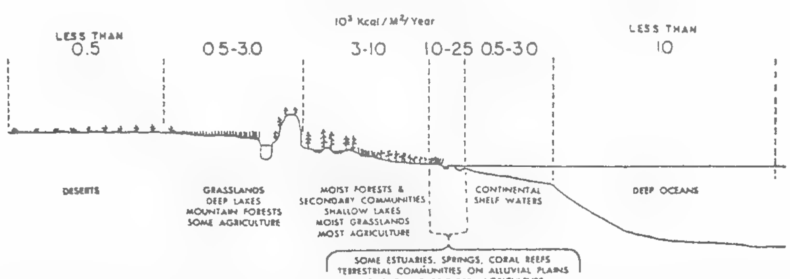
> Nowhere is the split between humanity and nature more dramatic than in the differing ways with which people and nature cover the land with vegetation. To maintain the ever-normal granary, agriculturalists favor the monoculture of annuals. Nature has, for the most part, favored the polyculture of perennials.
>
> Wes Jackson
> *The Land Report*

The trend of decreasing erosion with increasing presence of perennials suggests the ultimate strategy of using trees as major agricultural crops. To quote J. Sholto Douglas: "The tree is the tool with the greatest potential for feeding men (sic) and animals, for restoring water-systems, for controlling floods and drought, for creating more benevolent micro-climates and more comfortable and stimulating living conditions for humanity" (47). Perhaps the most striking advantage of designing with trees is that as biological elements they are self-repairing and self-perpetuating and their natural functions are powered by solar energy. The concept begins to appear more attractive as the various benefits are tallied next to the cost of alternatives (or the consequences of nonaction). To replace these benefits mechanically we must build erosion control works, enlarge reservoirs, upgrade air-pollution control works, improve water purification plants, increase air conditioning and provide new recreation facilities (15).

PRODUCTIVITY

The cumulative advantages of tree crops assume they produce a reasonable yield of food. J. Russell Smith in *Tree Crops* contended that trees could match row crops in both protein and carbohydrates in yield per acre. These are claims worthy of investigation, for if true, tree crops would present an attractive alternative to conventional agriculture in many regions. In compar-

TABLE 1



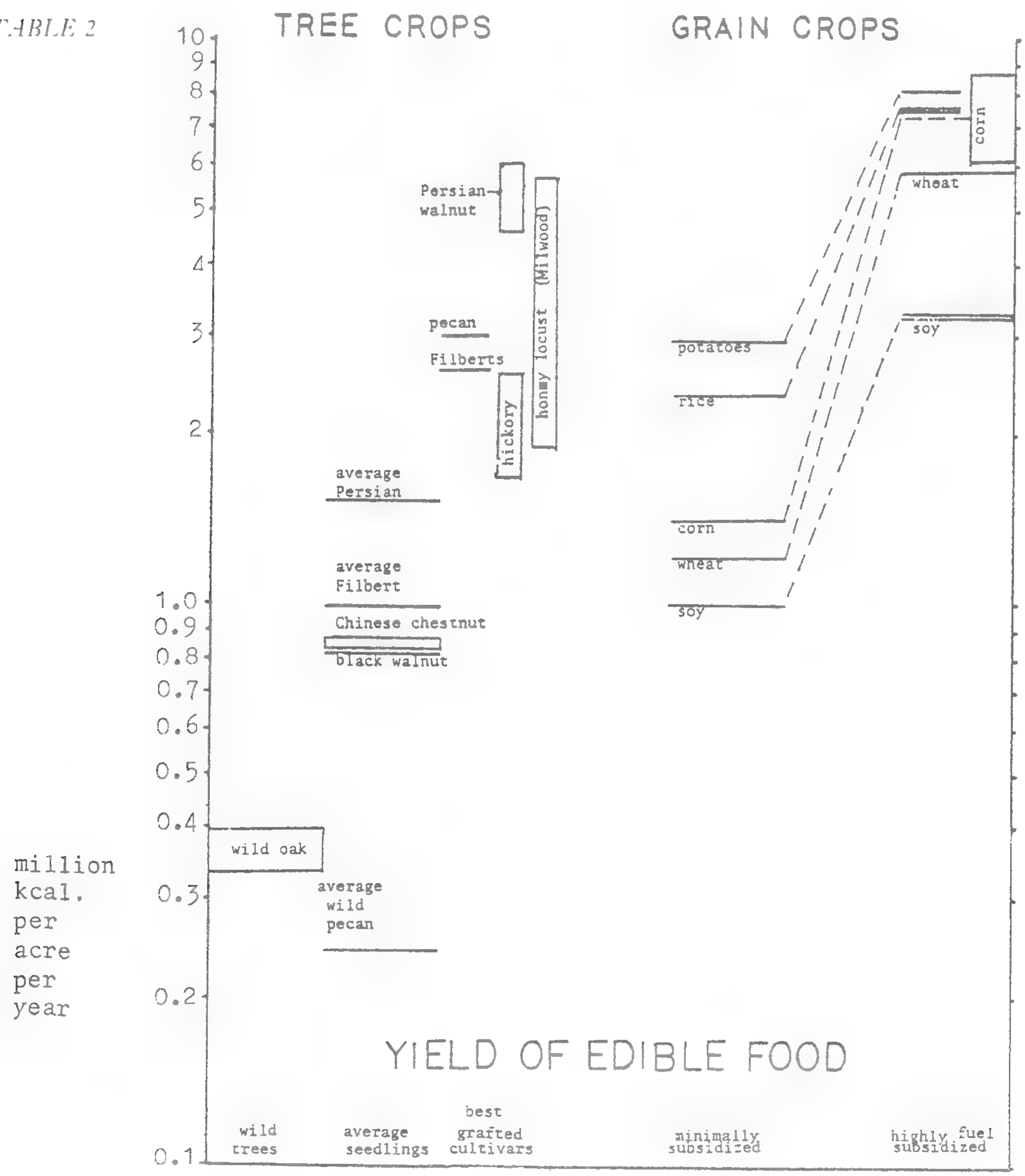
The world distribution of primary production in terms of annual gross production (in thousands of kilocalories per square meter) of major ecosystem types. Only a relatively small part of the biosphere is naturally fertile. (After E. P. Odum, 1963.)

ing ecosystems, ecologists place temperate forests and most agricultural land in the same range of primary productivity (Table 1). On a world average of crop production, growth in fertilized crop communities is generally lower than that in woodland; deciduous forests often approach twice the production of dry matter as grains in the same climate (7). Of course, total plant material is not as important as the edible part of the plant or crop. Wild forest trees yield only a small fraction of their biomass as edible food; domesticated crop plants can be nearly half edible grain. But recall that much of the tree's biomass which is nonedible comprises the structure that performs essential environmental services.

Domestication is a dual selection/protection relationship in which the farmer uses his skill and energy to protect a strain of plant that yields more food-to-fiber than the average of its kind. Artificial selection of crop plants does not normally increase the total production of the plant so much as it redistributes its productivity so that more goes into food and less into stems, leaves and roots. For example, in the last 50 years wheat has been bred to yield 66% grain-to-straw from the 51% grain-to-straw of earlier strains. This is not, however, the proverbial free lunch, since the energy rechannelled into food production is bred out of some other vital function of the plant. The improved strain will only perform well if the farmer is prepared to carry out the lost function. His work is called an energy subsidy to the crop, freeing it to concentrate its energy in food. Some common energy subsidies to conventional crops are pest protection, weed removal, nutrient enrichment and constant, adequate water.

If one compares energy subsidy to improved yield, early gains come cheaply. Food per acre from primitive

TABLE 2



farming using human/animal/fire energy can yield 100 times that of gathered wild food. Eventually, diminishing returns occur. Conventional agriculture in the United States has exhibited such a trend since 1945 (2). At high levels of energy subsidy, doubling of yields can require 3 to 10 times more energy. Evidently some ecosystem work is easier to subsidize than others. Often what appears to be a good management choice, such as monocropping to simplify cultivation, has high hidden costs of pest control and nutrient loss which must be paid eventually. It is an important challenge to discover which tasks are best performed by nature and which are best met with fossil fuels.

Table 2 is a yield comparison of edible carbohydrates from grain crops and tree crops. Two patterns that emerge are:

1. grain crops with high fossil fuel subsidy show higher yields than non-fuel subsidized crops, and
2. yields from improved tree crop cultivars are higher than wild or average seedling trees.

The best tree crop yields are seen to be approaching the level of subsidized high-protein grains such as soybeans and wheat. I believe that any difference is largely due to rapid genetic changes in annuals that allow a plant breeder to take advantage of new energy-rich technologies. Most tree species, particularly those native to North America, have received less intensive breeding research than have annuals. Preliminary steps have been taken, primarily through the efforts of dedicated amateurs: outstanding individual trees of most native American fruit, nut and forage types have been identified for qualities including high yields, annual bearing, cold hardiness and fruit quality (48, 49). In the process a few species such as pecan have showed rapid improvement through selection and are approaching yields of barley and soybeans. Table 3 shows the progress that has been made in identifying perennial crops that reach commercial production rapidly. It is both surprising and encouraging that the average time-to-commercialization is generally under 10 years.

ENVIRONMENTAL SERVICES

Remember that a tree invests some of its production as storage in branches, roots, twigs, and leaves. These are the parts that:

1. reduce forces of wind and rain;
2. capture and control rainfall;
3. filter the air of dust, ash, smoke, pollen, carbon dioxide, and aerosals;
4. reduce airborne sound with great efficiency;
5. provide generous shade at exactly the appropriate season to homes and urban areas.

In a timber tree (Table 4) the woody framework that performs these services is most of the tree. In domestication some of this wood must be given up in return for

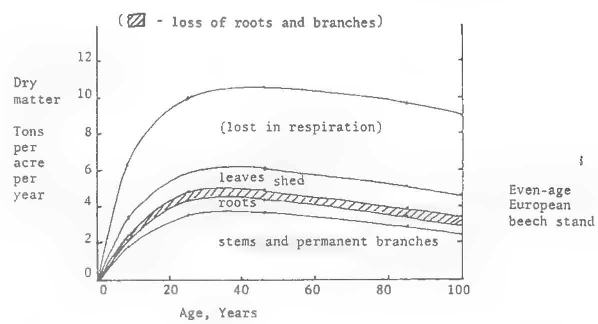
TABLE 3—Fruiting Age of Tree Crops

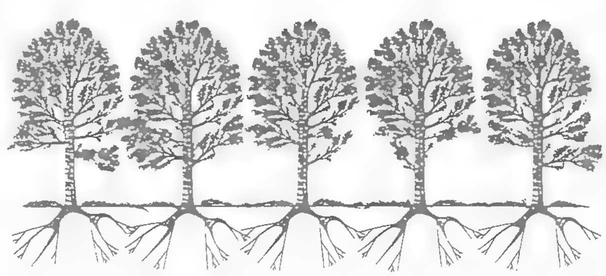
Perennial Tree Crop	*Years to bearing: grafted cultivars*	*Years to commercial production*	*Years to bearing: selected seedlings*	*Years to bearing: wild stock*
Commercial				
Almonds	4	6–7		
Apples	3–4	8–10		
Apricots		3–4		
Avocados		5–6		
Blueberries				
Chinese Chestnuts	2	10–12	5–8	
Cherries	4–6	10		
English Walnut		5–6		
Filberts		7		
Macadamia sp.			3–7	
Peaches	3			
Pears				
Pecans	3–4	7–10		
Non-commercial				
Black Walnut	6			12
Heartnut	2			
Hickory	3–4		10–15	40
Honey Locust		5		
Mulberry			5	
Oak	6–9			20–35

From Jaynes (1969); Reed and Davidson (1958); USDA Agricultural Handbook 450; the Fruit & Vegetable Association.

TABLE 4

PRODUCTION AND USE OF DRY MATTER





more food, yet even in the extreme case of dwarf apple there still is a significant physical structure that is of benefit to the human environment.

Food trees can serve multiple services in landscapes. Rather than just listing some of them, examples are presented in the following scenarios of tree crops used in rural, suburban, and urban settings.

DESIGN PRINCIPLES FOR TREE CROPS

1. Trees often serve multiple functions:
   soil enrichment
   food production
   soil preservation
   water control
   air purification
   creation of microclimates suitable for other plants, animals, and people.
2. In multi-story agriculture, lacy low-shade sun-tolerant upper-story trees form the upper canopy. Shade tolerant trees form the lower canopy. Pasture grasses and legumes form the ground cover beneath the trees. Meadows and field crops are rotated in open areas between groups of trees.
3. Nitrogen-fixing trees and shrubs are distributed through the landscape and contribute nitrogen to the ecosystem through leaf-fall, grazing or periodic cropping.
4. Orchards of domestic trees have the same general microclimatological effects as sparse natural forests (9).
5. More open, less dense stands of trees give the best yield per tree. With increased age, yield from a single tree becomes greater, but yield per acre tends to be fixed if the canopy is closed (10).
6. Pasture can thrive under tree canopies if they are not extremely dense and if nutrients are not limiting.

RURAL AGRICULTURAL FORESTRY

The only way man (sic) can have both a productive and a stable environment is to insure that a good mixture of early and mature successional stages are maintained, with interchanges of energy and materials.

Eugene P. Odum
Fundamentals of Ecology

The average American uses about 1 ton of grain per year, 93% utilized indirectly as feed for cattle, hogs and chickens, which supply our main protein sources of meat, milk and eggs (3). As energy costs rise, conventional meat production practices, which require considerable transportation of both animals and feed,

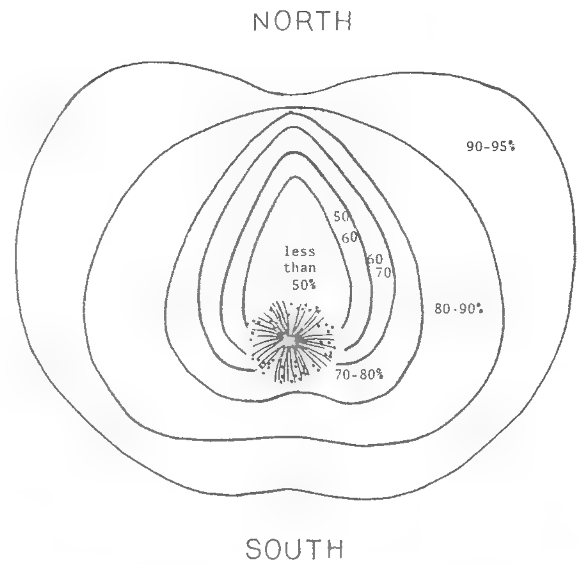


Figure 1. *Shade pattern produced around a standing tree, in percent of full sunlight. This pattern is for the spring season in central Europe* (after R. Geiger, *Climate Near the Ground*).

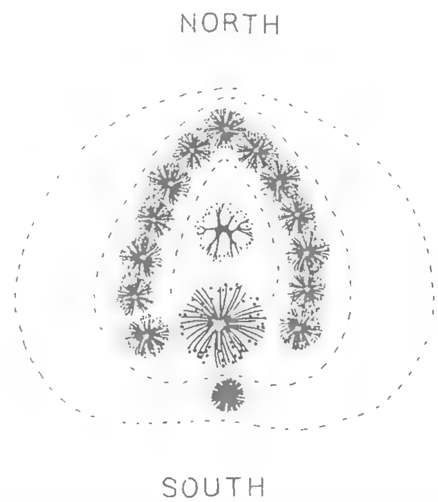


Figure 2. *Plantings around an established tree, matching shade zones with shade-tolerant species. Young tree on south side receives almost full sun and wind protection.*

Figure 3. *Cross section of amount of shade cast by an established tree.*

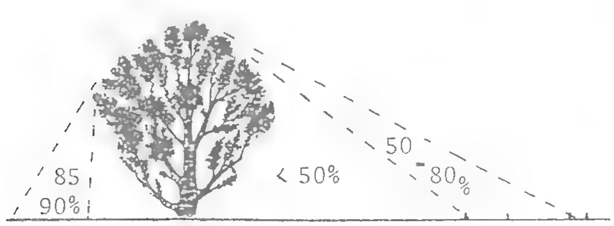
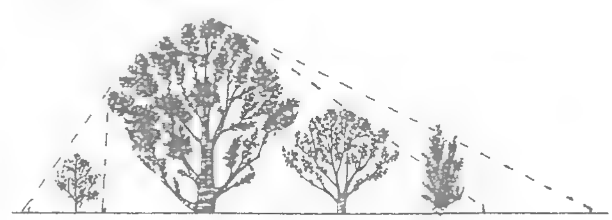


Figure 4. *Cross section of three rows, planted to optimize shade available and shade requirements of young species planted as original pioneer species grows.*



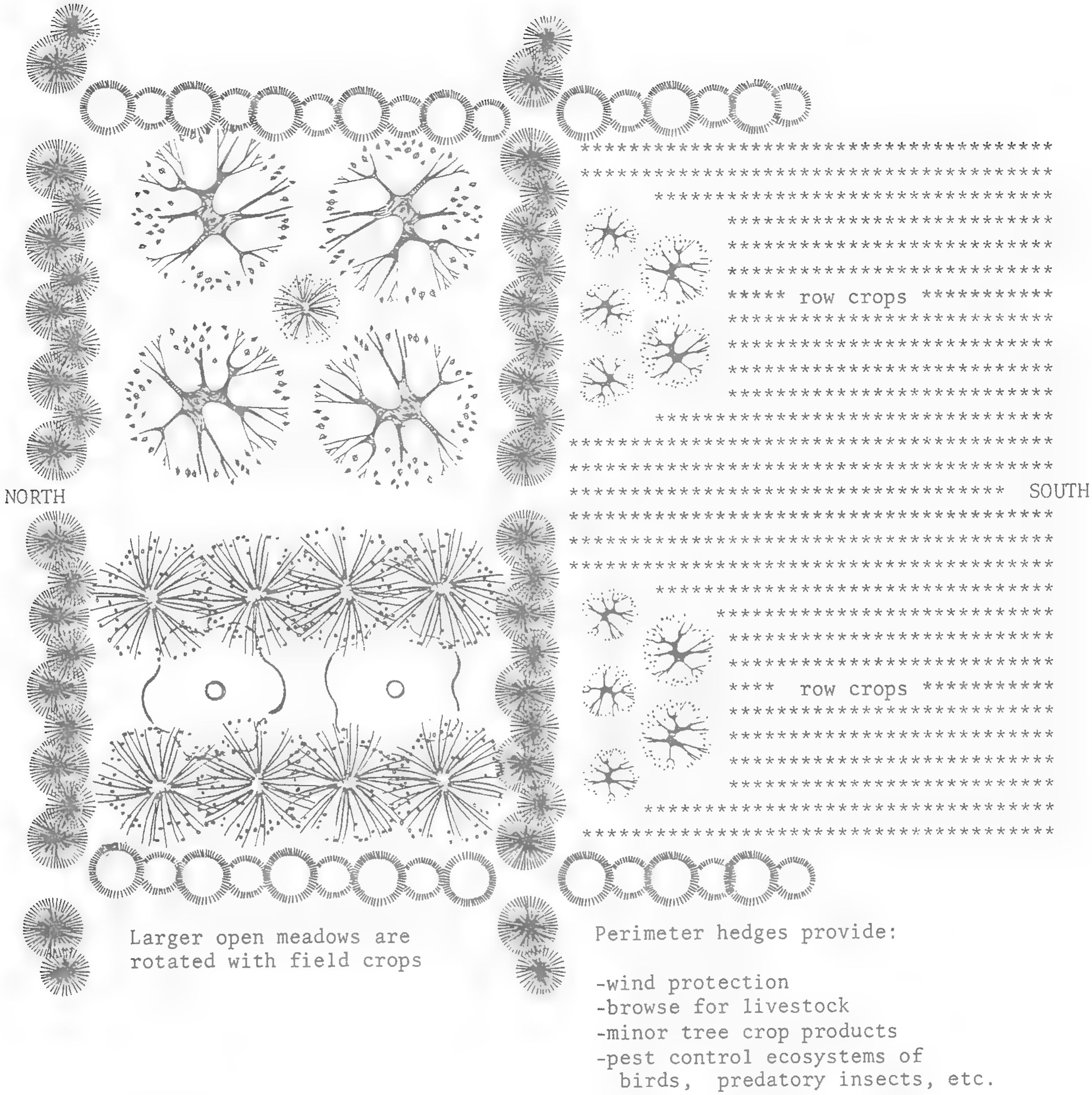


Figure 5. *Rural agricultural forestry.*

Figure 6. *Multi-story mixed tree crop agriculture, with livestock in understory pasture.*

will yield to growing feed and meat animals nearer to each other and to the consumer. The ultimate integration is to raise meat animals fed on grain and tree feeds produced in a matrix of fields and pastures protected by perimeter plantings of tree crops (see Figure 6). Large fields benefit from being sheltered; the approximately 5% area used for windbreaks is well compensated by higher productivity from the remainder. Nondomestic herbivores (wild game animals) are not to be shunned; highest sustained animal production from a given piece of land will most often result from a mixture of wild and domestic herbivores (7). Tree products such as acorns and honey locust pods can match corn and oats pound for pound as nutritious stored winter feed supplements for livestock.

URBAN AND SUBURBAN LAND

Approximately 11.7% of arable U.S. farmland is in municipal areas. This is comprised of about 40 million acres that have been converted to urban use, much of it the flattest, most fertile land available. Further, the rate of conversion is increasing (1). Every effort should be made to encourage productive use of this space for food production and increased environmental quality.

INSULATION OF BUILDING WITH PLANTED WINDBREAKS

Windbreaks of living plants have been well documented for their beneficial effect of reducing heat loss from buildings (8,9,17). The effect is due to reduced infiltration through cracks, reduced exterior convection loss, and in some cases reduced radiant heat loss. The net result is that a house with good wind protection on three sides (north/west/east) can reduce fuel use up to 30% in comparison to a similar house exposed to full wind. Windbreaks perform as insulation, just as other more familiar methods such as double glazing, materials in wall cavities and weatherstripping do. Like these other methods, establishing a windbreak has a capital investment cost, a maintenance cost, an expected working lifetime and a payback period that can be evaluated economically.

Unlike these other methods, windbreaks are biological and appreciate in value rather than depreciate. They improve their performance automatically, using available sunlight rather than an initial input of fuel energy of manufacture. It is thus a unique insulation technique which requires a relatively small investment in order ultimately to obtain large benefits.

The benefits of growing external insulation will be particularly useful to older homes which often have high infiltration rates and walls too thin for adequate amounts of wall insulation: both of these difficulties are amenable to the effects of a good windbreak. The strategy of growing insulation is an example of applying biological solutions to what is normally conceived as a technological problem. The concept involved is that biological systems (in this case, plants) maintain and perpetuate themselves using solar energy, while technological systems usually require energy of manufacture, maintenance, repair and disposal in the form of fossil fuels under the attention of people. In addition, while protecting from wind the plants can:

—produce food,
—preserve soil,
—control and purify water,
—filter air of dust, smoke, odors, and
—provide comfortable and pleasant living conditions.

Each of these services has values that become apparent when a community must construct substitutes.

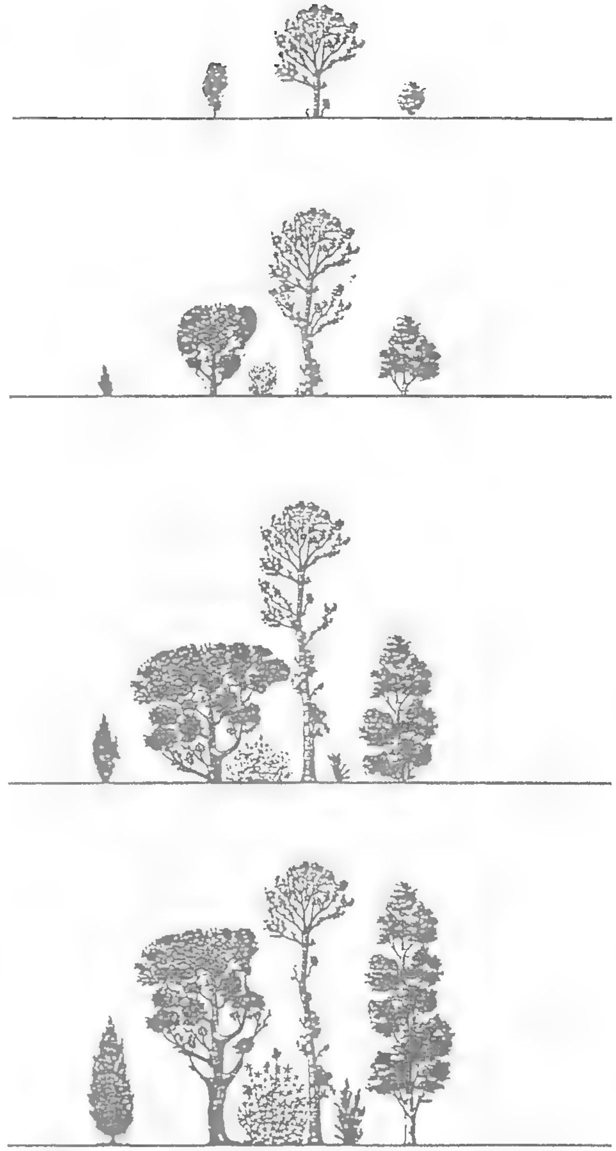


Figure 7. *Windbreak succession/diversification. As early sun-tolerant pioneer trees grow, resulting shade and wind protection provides microclimates for less hardy plants.*

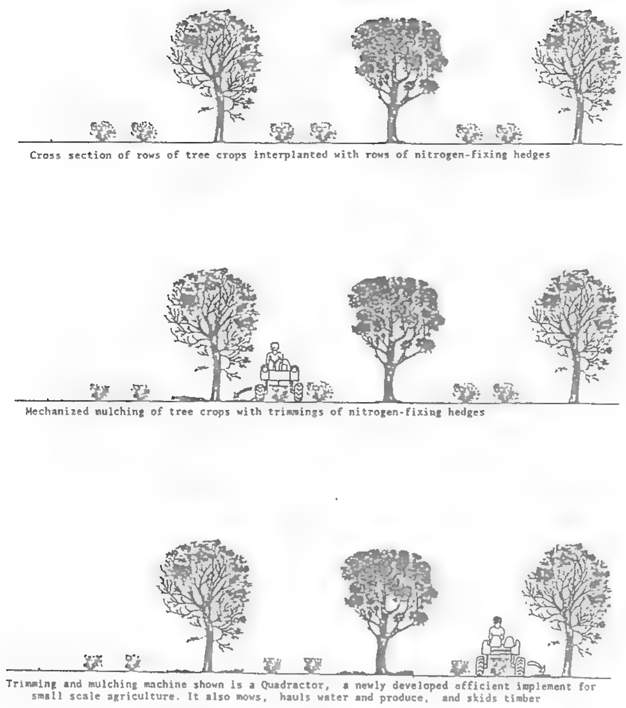


Figure 8. *Nitrogen-fixing hedges for sustained fertility.*

TREE CROPS FOR CONTINUOUS POULTRY FEED

In many respects poultry are ideal for homestead protein production. They recycle edible household and garden wastes, produce a high-protein food daily (eggs), meat occasionally, and require relatively little space and maintenance. They do need feed supplements to grass and garbage. Commonly this feed is commercial cracked corn or laying mash, thereby making the economics little different to buying eggs (apart from quality of egg). An alternative to purchased feeds is a combination of tree crops and perennial food plants. Suggested plants are:

Mulberry: for summer feed; drops mulberry fruit in great quantity for several months; a traditional animal feed in China.

Honey Locust: for fall feed; produces highly nutritious pods, which drop throughout late fall and early winter.

Burr Oak

Sawtooth Oak: for winter feed; acorns are storable and have feed value similar to corn, and can be ground like corn.

Comfrey: for spring feed; a high protein perennial herb devoured by chickens if given a chance. It leafs early in spring, and if grown in rows under semicylindrical wire protectors, the chickens have access to the daily growing tips without destroying the plant.

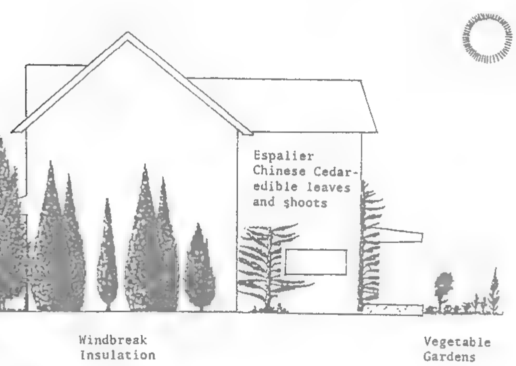
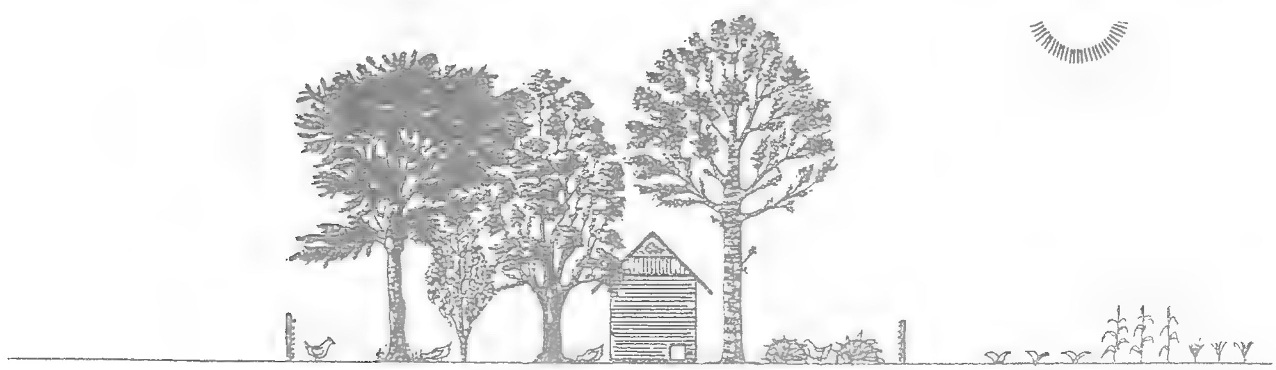


Figure 9.

URBAN LANDSCAPES

As energy supplies dwindle, urban populations will undergo major changes that will involve transportation, work places and the relative value of food. One option for city dwellers is to convert space now committed to transportation over gradually to agriculture. By encouraging associations of street residents to transform segments of street into street gardens with pedestrian/bike corridors, a city can slowly foster local food production and mass transit. The following description and illustrations suggest details of such a transition.



1970's Normal Urban Street

1. Surfaces of sidewalks, streets and buildings result in glare, great temperature rises in summer and great run-off of rainfall.
2. Lawns and shrubs are primarily ornamental.

Transition to Greater Use of Street Space

1. Block-long segments of North–South streets are zoned for pedestrian, bicycle and moped traffic, with assurance of mass transit and car parking at the ends.
2. Street gardens are constructed over existing pavement, retaining street drainage and sewer system.
3. Tree crops, gardens and insulative windbreaks are established.

Mature Urban Agriculture

1. Household vegetable gardens, solar aquaculture and tree crops provide local food supplies.
2. Normal city water supply provides households, which then recycle graywater from washing and showers to trees and gardens.
3. Increased plant cover moderates temperatures, purifies air and absorbs rainfall. Plants also greatly reduce glare and noise.
4. Some of the street garden structures are greenhouses using waste heat from local light industries to supply winter food and garden seedlings to the neighborhood.

ENVIRONMENTAL QUALITY AND URBAN AGRICULTURE

On hot sunny days, temperatures in urban areas normally rise quickly because of high reflection and radiation from sidewalks, streets and building. The result is discomfort and extensive use of air-conditioning. In contrast, when sunlight strikes a plant surface, much of it is absorbed to evaporate water. Temperatures over grassy surfaces on a sunny day are 10–14°F. cooler than on exposed soil or street surface for this reason (8).

As water makes up 80–90% of a plant's biomass, the heat capacity of the water absorbs radiation and releases it later slowly. Both processes combine to moderate fluctuations in temperature and humidity, making conditions more comfortable to life. Trees provide shade for the great benefit of people and solar buildings at exactly the appropriate seasons. Deciduous trees even adjust to cold extended springs by leafing out later, and long warm falls by dropping leaves later.

Atmospheric Contaminants

Streets with trees have been shown to have about one third the amount of airborne dust of streets without trees. Dust, soot, smoke, odors, and other particulate matter are similarly removed from the air. Gases such as CO_2 are actively taken up. Lead from auto exhaust tends to accumulate on the soil, often in dangerous concentrations. Preliminary tests in Boston of tree fruit grown in soil with 3,000 parts per million of lead showed no lead in the fruits.

Noise as an atmospheric contaminant is greatly reduced by tree stems and leaves; trees are often planned by highway designers to block freeway traffic sounds from residential neighborhoods. Noise reduction effectiveness has become quite well quantified as a result.

These various environmental effects are quite valuable:

> These natural functions are powered by solar energy, and, to the degree that they are lost, they must be replaced by extensive and continuing investments of fossil fuel energy and other natural resources. If the quality of life is to be maintained, we must build erosion control works, enlarge reservoirs, upgrade air pollution control technology, install flood control works, improve water purification plants, increase air conditioning and provide new recreation facilities.*

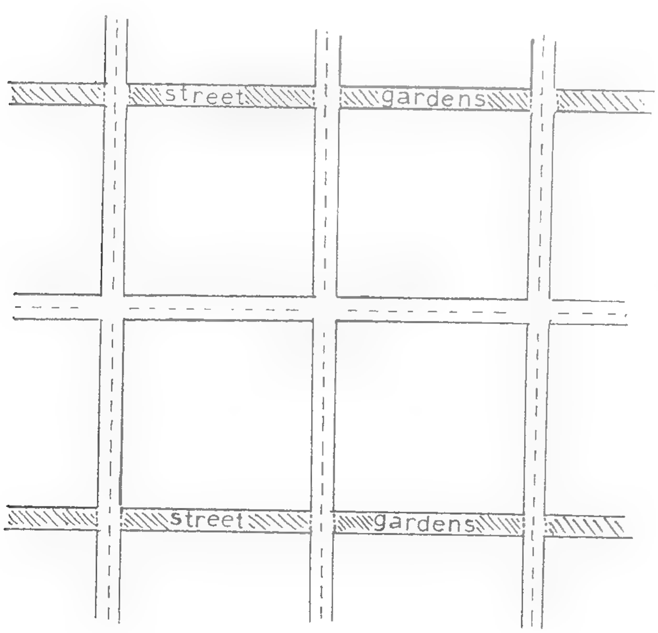


Figure 10. *Urban space re-allocation. North-south street segments between city blocks are gradually changed from roads to street gardens. North-south avenues receive sun equally on both sides of the street.*

*F. H. Bormann, "An Inseparable Linkage: Conservation of Natural Ecosystems and the Conservation of Fossil Energy," *BioScience*, 29, No. 12: 754–60.

Figure 11.

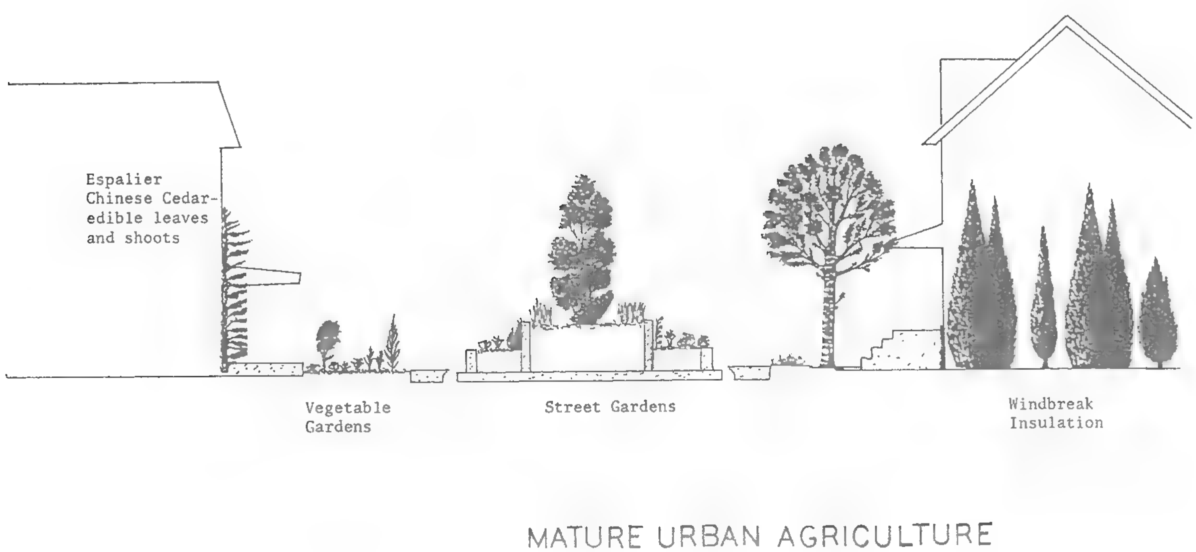
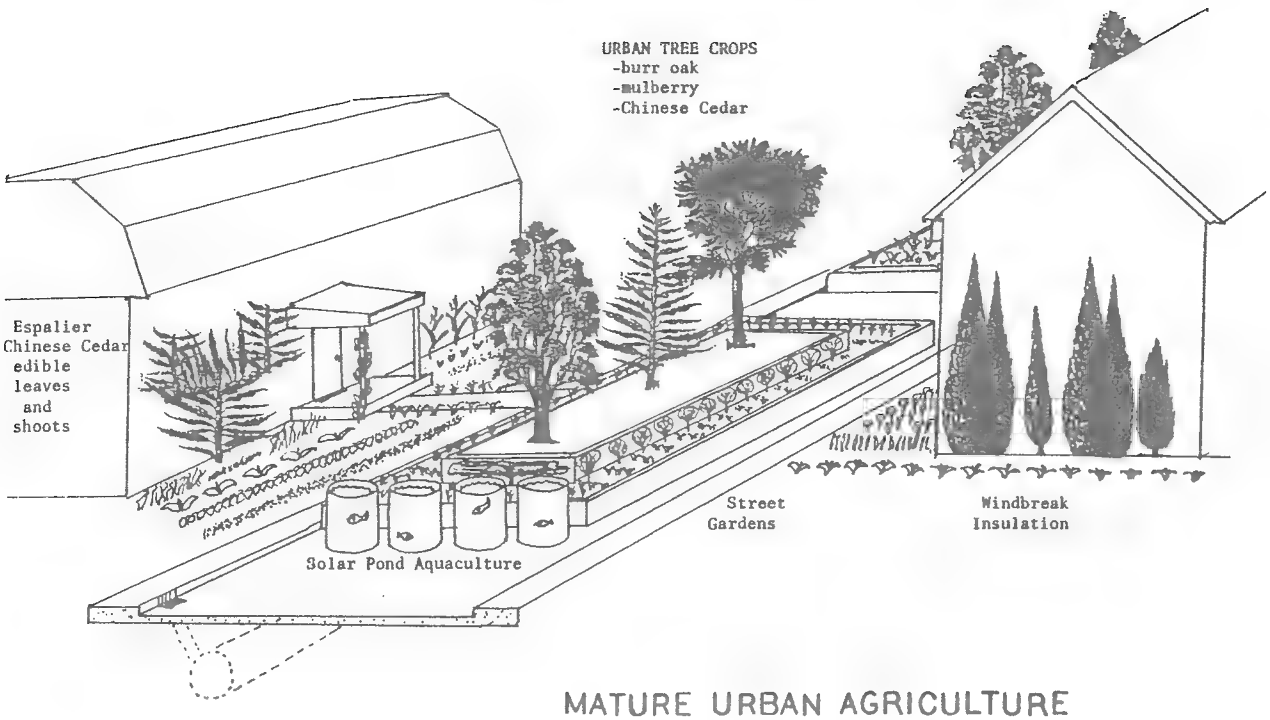


Figure 12.



MATURE URBAN AGRICULTURE

PROPAGATION OF TREE CROPS

The selection and propagation of trees for agricultural purposes can produce wondrous crops from relatively insignificant ancestor plants. Crab-apple ancestors were selected over time to create today's apple. More recently in the United States the southern pecan has been transformed from a wild hardshelled small nut to the paper-thin-shelled nuts of modern commerce. Each native fruit, nut and forage tree species has much genetic variability in such qualities as size and taste of fruit, age at first bearing, annual consistency of yield and ease of propagation. By finding an individual wild tree with one or more of these traits and propagating it into many identical trees, one can create orchards of high productivity. These can be later cross-pollinated with other outstanding cultivars and can result in a next generation of multiple good traits.

There is a striking difference in the ease of vegetative propagation between long-domesticated tree crops such as apple, mulberry, fig and grape and wild trees such as walnuts, hickories, oaks and paw-paws. Over centuries of cultivation and migration the trees in the first group which were most easily and successfully propagated were the ones to spread to new lands, becoming easier and easier to propagate in the process. Forest trees, on the other hand, are in nature selected by a multitude of forces for many qualities, and consequently they show a wide variability in their capacity to root or graft successfully.

For agricultural forestry research we would like to use many of the native species, in addition to proven foreign species such as Persian walnuts, Chinese chestnuts and Oriental persimmons, adapted to American soils and climates. These species are relatively difficult to propagate, but the following propagation techniques show promise of more rapid and successful results than those currently practiced.

OBTAINING SUPERIOR CULTIVARS

Over the past several centuries of land use in the United States, the clearing of forests for agricultural use has considerably reduced the genetic scope of native tree crops. Some have become endangered species (53). Yet because of their recognized utility, they have often been spared by the farmer when clearing land to provide food for himself or his livestock (19). Thus good trees have been preserved in fencerows, pastures, and farm woodlots. Over the subsequent years many outstanding cultivars have been named by members of the Northern Nut Growers Association and the North American Fruit Explorers (48, 49), whose members are mostly amateur plant appreciators who have discovered much of what is known about the growth habits and propagation methods of native food plants.

Many of the best cultivars known of noncommercial species are found only in a few private collections of members of these organizations and are propagated irregularly if at all. A few of the most popular can be

Photo by R. D. Zweig

purchased commercially, and many can be custom-grafted with advanced notice, but to our knowledge no large arboretum or nursery of native food plants has been established. For valid comparison of varieties, we propose collecting many of the named varieties for propagation and field experimentation. Existing collections by past researchers offer the best access to plant material. Of particular interest is the remaining tree collection of the late J. Russell Smith, a noted pioneer in the concept of tree crops. In the first half of this century, Smith collected superior food tree cultivars from across the United States and established them for observation at his nursery near Round Hill, Virginia. A few of the species obtained by Smith during this period, such as the Chinese chestnut and various strains of the Oriental persimmon, were imported and have since become widespread and valuable commercially. World War II stopped all work at the site and the serious research ended. The site has since become overgrown and unused.

On several occasions, subcollections of Smith's best trees were transferred to other sites for farm-scale testing. Most notable of these are the direction of the T.V.A. in Tennessee and a site in Pennsylvania under the direction of John Hershey. In each case the man in charge fell ill and the collections were virtually abandoned although portions of the tree stock are still intact. These three sites are of ardent interest in resuming the tree research of these men. It is likely that many of the superior trees on each place have produced chance hybrids that could be superior to the parents. These are the only places where tree crops of many types are growing in a forest-like condition so that a study of the relative ability of each variety to exist in a mature canopy situation would be possible.

J. Russell Smith's family, the present T.V.A. staff, and Mrs. Hershey have all assisted and encouraged efforts at exploring the possibility of re-evaluating the remaining tree resources. If research support is found, we propose to:

1. identify remaining tree varieties,
2. observe chance hybrids in the vicinities for superior quality,
3. collect and distribute valuable cultivar scions to other researchers and commercial nurseries,
4. clear underbrush and provide permanent labels for known varieties, and
5. write evaluations and recommendations for future development.

It seems appropriate that a serious study of the tree crops concept should pick up where its foremost proponents left off.

NURSE-SEED GRAFTING

An outstanding nut-tree cultivar is normally propagated by grafting one of its branches onto a young nut-tree seedling of the same or of a closely related species. This operation requires considerable skill, time and seasonal accuracy. The final expense is high, which is the major constraint on large-scale availability of many important nut trees.

An alternative, relatively new technique called "nurse-seed grafting" (first described in 1964) offers several potential advantages over normal outdoor spring grafting:

1. The rootstock is sprouted nut seed; normally two years are required to grow a large rootstock for grafting.
2. Timing and weather are not critical; the grafting can be carried out at an indoor table or greenhouse bench over several months.
3. The technique is relatively simple, requiring less skill than conventional nut-tree grafting.
4. Initial root-scion compatibility can be determined within 4–5 weeks without long and expensive nursery growth of rootstock.

The basic procedure is summarized in Figure 14. Most research to date has been on Chinese chestnuts, avocadoes and camellias. Limited trials have also included oaks, pecans, walnuts and some of the drupe fruits such as peach or plum. Success has varied considerably, ranging from 88.9% with certain chestnut stock-scion combinations to little success with mature oak scions or cross-species grafts. A very limited number of species and cultivars have yet been tested. This technique offers an efficient method to test quickly and to mass propagate many unavailable cultivars.

A germinating nut is cut to allow a thin-wedged dormant scion to be inserted at the point of root/shoot growth. A modified method is to insert the scion into the split hypocotyl. The graft is then placed in a warm medium for healing and rooting. It is later moved to a nursery of the field.

PLASTIC TUBE CULTURE OF TAP-ROOTED TREES

Many tree species which are highly valuable for production of food or forage normally grow a long taproot as seedlings. Walnuts, hickories, many oaks, pawpaws, pecans and horse chestnuts are all examples of food trees that tend to be avoided by commercial nurseries because of the difficulty of digging and successfully transplanting them. A taproot without room

REFERENCE FOR FIGURE 14

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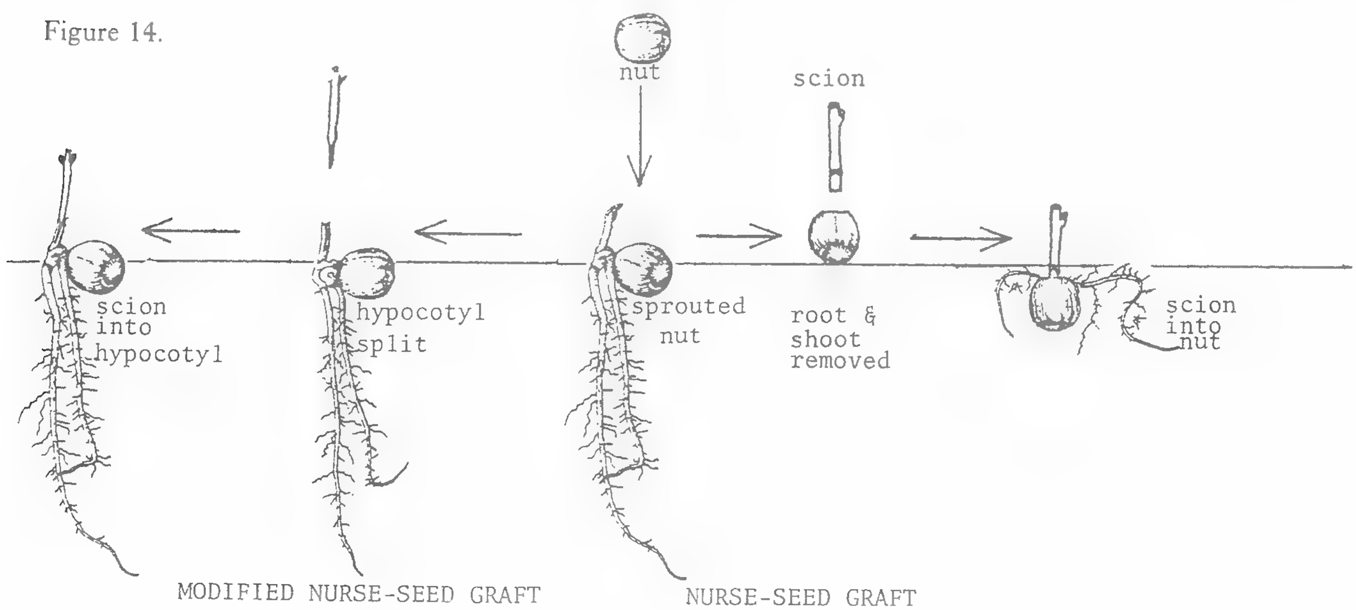
Park, Kyo S. 1968. "Studies on Juvenile Tissue Grafting of Some Special-Use Trees," Korean Journ. Botany, *11*, No. 3: 88–97.

Figure 14.



to develop results in a stunted tree; a taproot damaged in early development seriously reduces the viability of a young tree. Often tap-rooted trees stored and shipped barerooted fail to survive (19).

A promising solution to propagation and shipping of such trees has been developed for pecans. The technique uses inexpensive polyethylene tubing as deep containers for seedlings, which allows normal taproot development. The seedling can be budded or grafted while growing in the tube. When needed, the seedling is carried in the tube to its final field location, where the tube is removed and the rooted seedling is slipped into its hole. Transplanting shock is minimal and the season during which planting is possible is greatly increased over conventional bare-rooted dormant stock.

The use of this method is ideally suited to small-scale nurseries, eliminating the need for digging machines or expensive containers normally used for the same purpose (barrels or lath tubes).

REFERENCES FOR FIGURE 15

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Hinrichs, H. A. 1976. "The Effect of Supplemental Light on Growth of Seedling Pecan Trees Grown in Plastic Tubes," Northern Nut Growers Association Annual Report, *67*: 90–92.

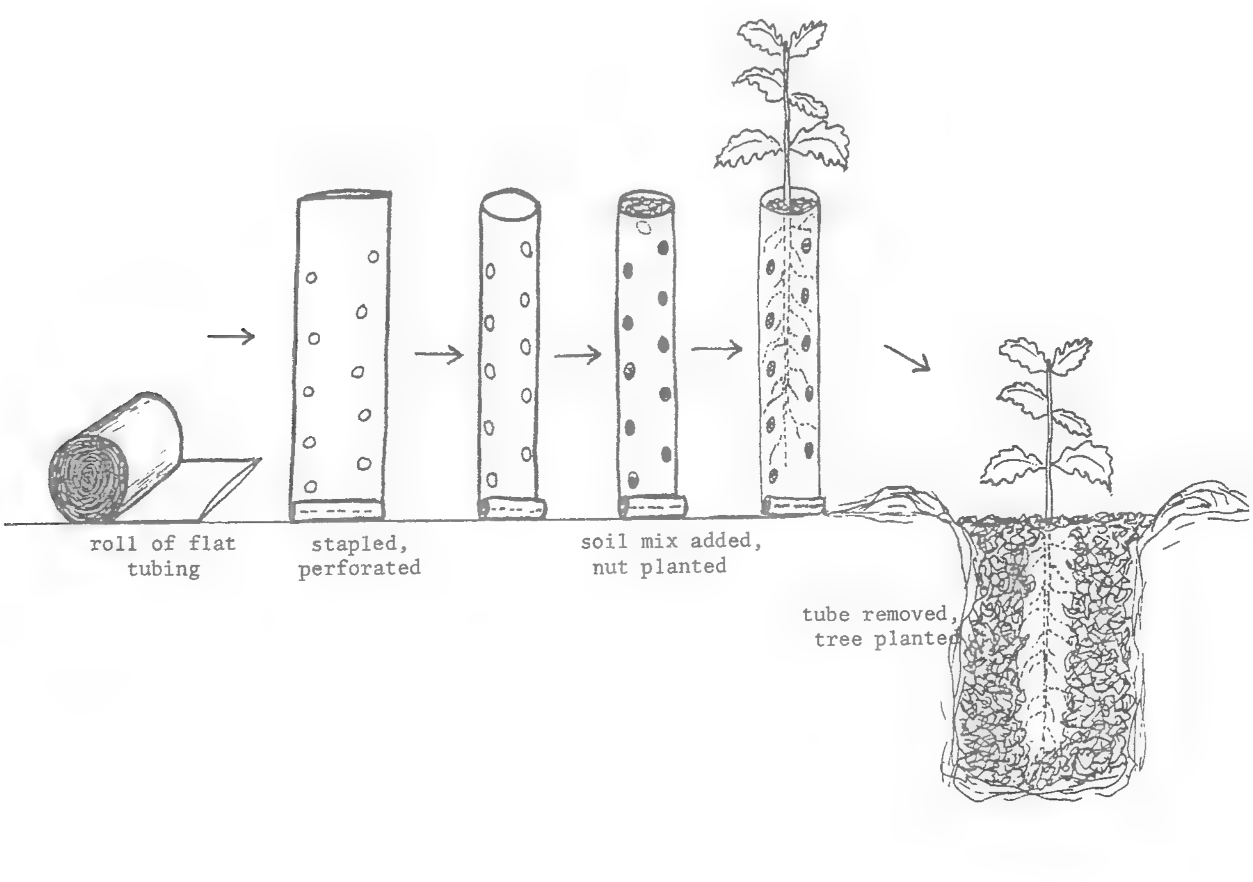
TESTING NUT QUALITY OF YOUNG TREES

Systematic tree-crop improvement requires growing and evaluating hundreds of young seedling trees. These seedlings are usually the result of cross-breeding of two high-quality parents in hopes of getting an even better hybrid. Unfortunately there is a long wait until the young seedling produces nuts for evaluation of quality. It can take from 10 to 12 years for walnuts and hickories. This waiting period can be reduced by 4 to 6 years if a branch of the seedling is grafted to a mature tree, forcing it into early fruiting (19). Such grafting is subject to difficulties of incompatibility between stock and scion, high skill and labor requirements and the necessity of maintaining mature stock trees.

A much easier technique to hasten nut production has recently been described by Stoke (51). In several different tests with black walnut he chose a small minor branch of a walnut seedling that had never produced nuts and girdled it with a band of copper wire during one growing season. The band was then removed in the fall. The next summer that limb alone produced a good crop of nuts. The forcing effect did not carry over to the next summer.

Tree physiologists have reported similar early fruiting in other species as a result of controlled girdling (52). These observations suggest that seedling trees

Figure 15. *Plastic tube culture of tap-rooted trees.*



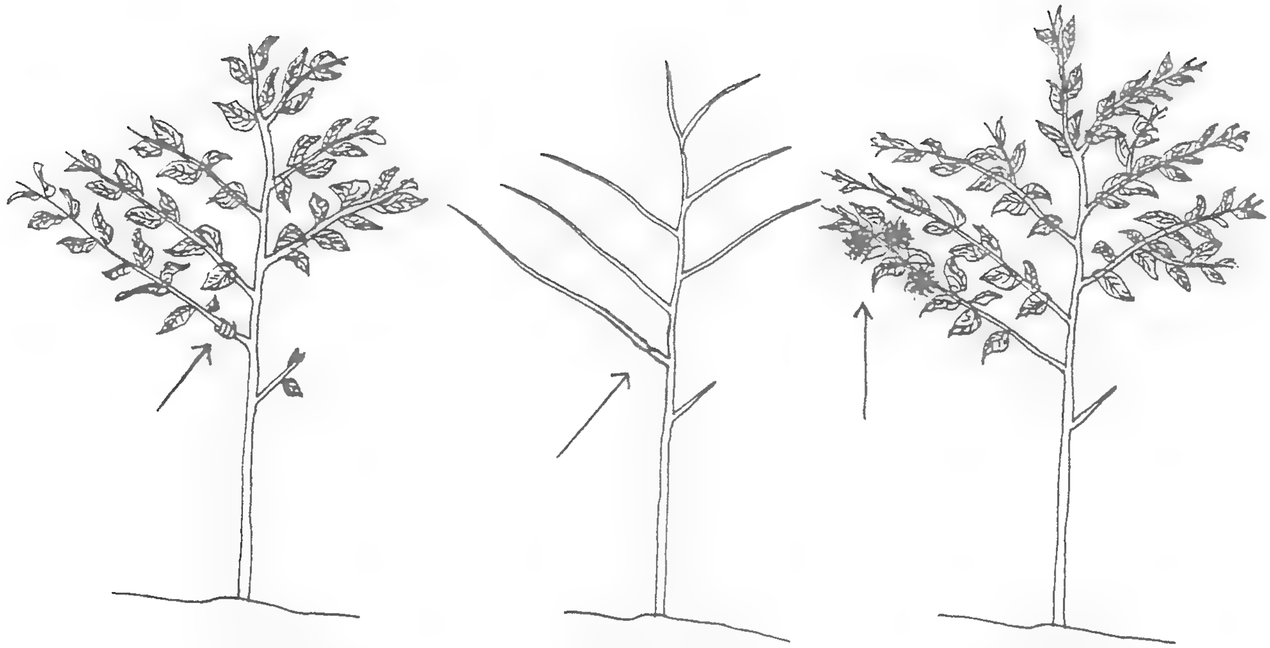


Figure 16. *Early fruit quality testing by controlled girdling.*

under observation in nursery rows could be induced to fruit at a very early age to quickly eliminate inferior trees. The technique would provide a simple way to test seedlings growing in the wild when thinning is necessary. Perhaps most important, early induced flowering and fruiting would make possible rapid genetic manipulation and tree breeding progress. Research on the effectiveness of the technique would be fairly simple. Commercial nursery stock of oak, walnut, hickory and other slow-fruiting seedlings can be tested to determine optimum seasons and duration of controlled girdling that produces earliest fruiting without permanent damage.

EPILOGUE

Forests perfom irreplaceable ecological services as well as provide economic products and recreation. They assist in the global cycling of water, oxygen, carbon, and nitrogen. They lend stability to hydrological systems, reducing the severity of floods and permitting the recharging of springs, streams, and underground waters. Trees keep soil from washing off mountainsides and sand from blowing off deserts; they keep sediment out of rivers and reservoirs and, properly placed, help hold topsoil on agricultural fields. Forests house millions of plant and animal species that will disappear if woodlands are destroyed.

Erik Eckholm
"Planting for the Future:
Forestry for Human Needs,"
Worldwatch Paper 26, 1979.

REFERENCES FOR FIGURE 16

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Stoke, H. F. 1975. "Girdling to Hasten Nut Production." *The Nutshell,* 27, No. 2: 3.

The ecological advantages of tree crops are quite obvious; the economic consequences are more subtle. Good ecology and good economics often appear to be in conflict when viewed over the short term. But a time-frame of several generations or several centuries reveals an "economics of permanence" in which ecological well-being of a settled people is *identical* to economic well-being. Our present economic theories of investment and profit fail us as a basis of permanent community or cultural security. The drive to maximize profit results in constantly searching for and exploiting greener pastures rather than nurturing the lands at hand. The period of human history is ending in which migration can avoid the consequences of careless stewardship; we now face the difficult task of coming to terms with nature.

Forging of a land ethic which carefully considers global and future consequences is now paradoxically only possible by using fruits of knowledge and technology produced by the civilization which has made such a task crucial. Our energy-intensive, medically protected society is immune to the population controls most species face, while the mechanical power and

technical knowledge we control can displace almost any natural community. Necessary ecological feedback, which in nature operates at a subtle structural and behavioral level, must in our case become conscious and monitored with a large dose of communicative technology. The traditional knowledge of past cultures and present science is available for reconstructive design of human landscapes. Air and water quality can become sensitive indicators of stress and degradation of ecosystems, with the aid of low-energy electronic computation and communication systems to pinpoint and communicate sustainable levels.

Materials technology offers long-lived tools, shelter, and agriculturally useful membranes for plant and animal management. Perhaps most importantly, remaining fossil-fuel supplies permit transportation and distribution of available nutrients, biotic species, and soil conservation structures that will allow regionally self-reliant agricultures to become established.

Tree crops and other agricultural perennials are important elements in agricultures of the future. They are resilient, self-maintaining food producers which automatically perform services and functions now subsidized by fossil fuels. Their culture and maintenance require relatively simple tools and easily acquired skills. Eminently suited to rocky hills, urban, suburban and other landscapes not considered agricultural, they offer the best compromise between food production and landscape amenities, and between environmental protection and materials production.

Creative design of agricultural landscapes using tree crops is in a very early stage; farmers, orchardists, city planners, foresters, and ecologists have only begun to cooperatively explore the merger of their knowledge and recognize the concept of an agricultural forestry. Many agricultural trees and plants used for centuries in various biogeographical regions have only recently become available in other similar bioregions as potential agricultural crops. Extinctions and continuous distribution of plant and animal species around the biosphere has nearly eliminated the chance of retaining "natural" ecosystems. Thus ecological designers must now begin to create a symbiotic community of plants, animals, and humans with the visionary goal of permanently sustaining them all.

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New Alchemy Tree Crop Research

Paula Gifford and Earle Barnhart

The following article on mulberry productivity is one of a number of special tree-crop research papers intermittently being produced for communication with other tree-crop researchers and associates. They are special-topic reports on aspects of tree crops, tree culture, and agricultural forestry design that we have found to be useful or important in our work. The series is called "New Alchemy Tree Crop Notes" and includes:

- NO. 1 Bibliography of Agricultural Forestry
- NO. 2 Organizations, Groups and Individuals Involved with the Tree Crops
- NO. 3 New Alchemy Mulberry Yield Measurements, 1978
- NO. 4 New Alchemy's Tree Crops Research, 1978–1979
- NO. 5 Nurse-Seed Grafting of Trees
- NO. 6 Plastic Tube Culture of Tap-Rooted Trees
- NO. 7 Controlled Girdling of Trees for Early Quality Testing
- NO. 8 Feasibility of Domesticating Squirrels as Nut Gatherers
- NO. 9 Windscaping with Trees
- NO. 10 Beescaping with Pollen and Nectar Plants
- NO. 11 Sources of "Antique" Hardy Domestic Animal Varieties
- NO. 12 Willow Coppicing for Fuel, Fiber and Forage

Serious tree crop workers may obtain copies (at printing cost plus mailing) by contacting Earle Barnhart, The New Alchemy Institute, P.O. Box 47, Woods Hole, Mass. 02543.

Mulberries represent a valuable food for human consumption and animal feed. J. Russell Smith in *Tree Crops* describes a region in Afghanistan where dried mulberries (*Morus alba*) are a major staple. In the southern parts of the United States, mulberry trees were often found in pastures for pigs and poultry, providing feed which was harvested by the animals as it fell. Several varieties described as "everbearing" bear from May to August in the South.

Our harvest measurements indicate that on Cape Cod a mature tree can yield over 400 pounds of collectible fruit, plus an additional amount taken by birds and squirrels. I have extrapolated this yield to 5.68 tons per acre. On such a scale the fruit would best be collected directly by the foraging animals, and various cultivars should be interplanted to give a longer, sustained yield of many months.[1]

Nutritive information on mulberries is scarce and probably nonexistent for the United States. USDA sources do not mention mulberries as either human food (USDA Handbook #72; 1971, covering 2,483 food items) or as animal feed (*Atlas of Nutritional Data of the U.S. and Canadian Feeds;* 1972).[2,3] The only clue is an analysis of the dried mulberries used in Afghanistan, which shows them to have about the food value of dried figs.[4]

Individuals of the North American Fruit Explorers are the only people we know in this country researching mulberry cultivars.[5]

Mulberry Yield—1978

Fallen fruit was harvested from a mature mulberry tree (*Morus alba*) with a trunk diameter of 22 inches and a canopy spread of approximately 1,553 square feet. Fruit was collected daily over 30 days from netting on the ground which intercepted approximately 75% of the canopy spread (1,144 square feet). Birds and squirrels consumed an additional unmeasured quantity of fruit. Marketable fruit was processed for human consumption (70%) and the remainder (30%) was fed to young chickens.

Collection from 74% of the canopy area yielded 135.7 kg. of fruit. Total collectible yield was estimated to be approximately 184.2 kg. (405.2 lbs.). Distribution of yield from June 28 to July 28 is shown In Tables 1 and 2. Unmarketable fruit was eagerly eaten by young chickens.

[1] J. Russell Smith, 1950, *Tree Crops: A Permanent Agriculture* (Devin-Adair Co.), pp. 97–109.

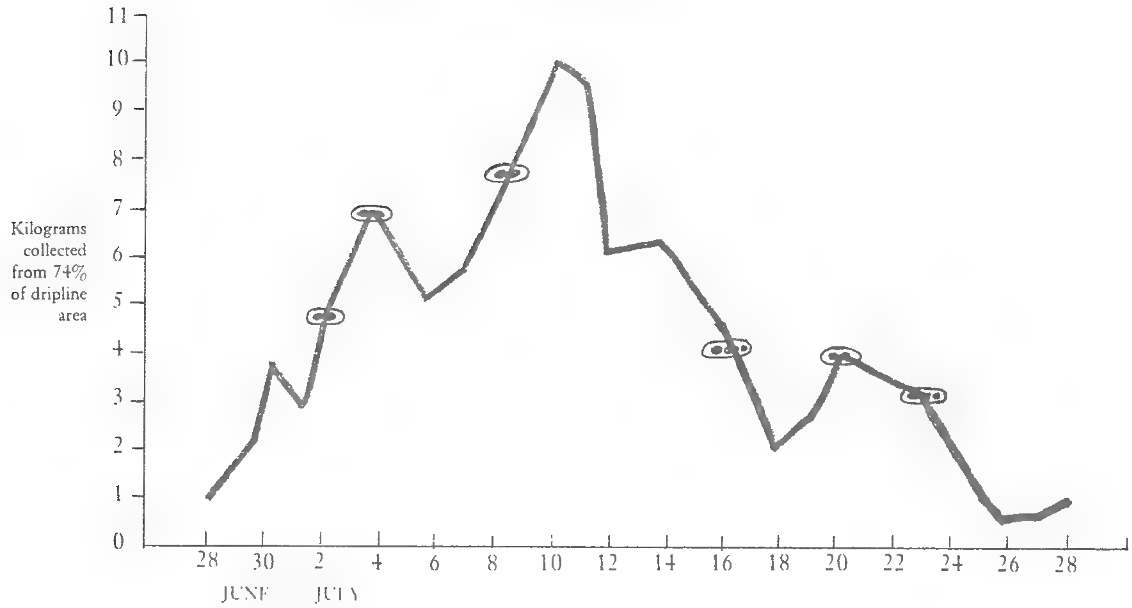
[2] U.S.D.A. Agricultural Handbook No. 8, December 1963; 190 pp. covering 2,483 food items.

[3] *Atlas of Nutritional Data of U.S. and Canadian Feeds,* 1972, National Academy of Sciences.

[4] Smith, op. cit., pp. 107–8.

[5] North American Fruit Explorers, 1848 Jennings Drive, Madisonville, Ky. 4231.

TABLE 1—Yield of Fallen Mulberries: 1978



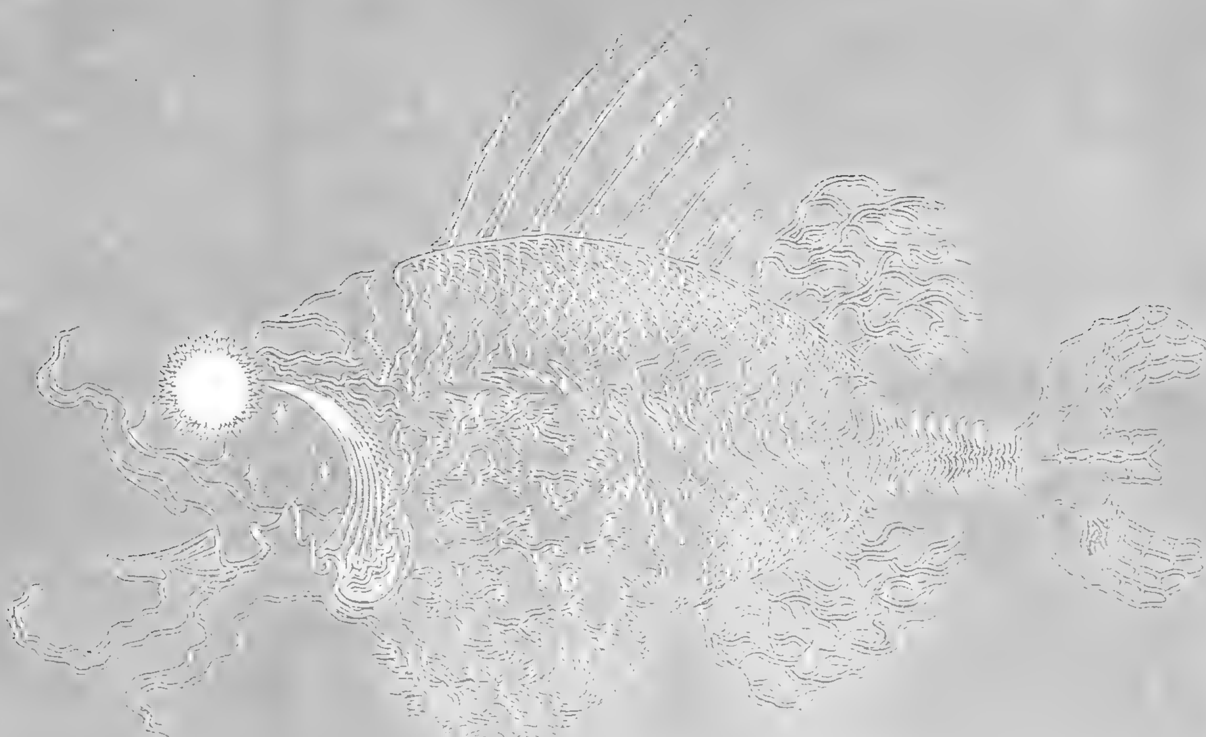
(Double and triple points on graph are two and three day accumulations averaged over the period.)

TABLE 2—Harvest Data

	Gms.
June 28	760
29	2,045
30	3,940
July 1	3,256
2	(*)
3	9,768
4	(*)
5	14,542
6	5,060
7	5,596
8	6,395
9	(*)
10	16,099
11	10,266
12	9,960
13	5,841
14	6,143
15	(*)
16	(*)
17	12,810
18	1,314
19	1,684
20	3,816
21	3,915
22	(*)
23	(*)
24	10,572
25	785
26	330
27	340
28	458
TOTAL	135,695 gms. or 135.7 kg

(*) Fruit not collected until next day.

Drawing by Hilde Maingay



Aquaculture

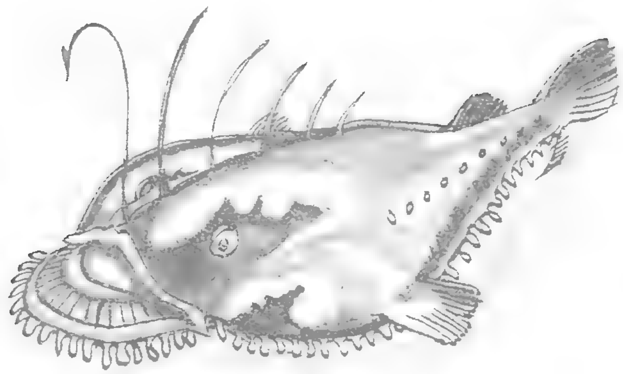
Our aquaculture research at New Alchemy is probably among our most innovative. Its goal is pretty pragmatic: to explore ecological and economic ways of growing protein. Should a rationale beyond obvious need be needed, John Todd's article, "Where Have All the Fishes Gone?" makes clear that aquatic as well as terrestrial and aerial forms of life are endangered as things now stand. But like so much of our work that begins with a gloomy or doomwatch prognosis, this is sometimes offset by encouraging courses of action that open up to us. This is borne out in the success story told by Bill McLarney and Jeff Parkin in "Cage Culture."

The next piece, "Biological Filters," by Michael Connor, describes an experiment that he conducted at New Alchemy in the summer of 1978. Michael is a doctoral student in biology at Woods Hole Oceanographic Institution. His work has provided us with some useful and relevant information.

The series of articles that follow this first section, subsumed under the umbrella title Solar Aquaculture, with contributions by Ron Zweig, John Wolfe and David Engstrom, covers our most recent work with aquaculture in artificially simulated, semi-closed ecosystems. The first article by Ron on the Domes explains how our fish get their start in life in a subsurface pool in a small geodesic dome. The rest of the series is concerned with observations of the solar-algae ponds which are five-foot-high translucent cylinders that contain sunlight-driven ecosystems of surprisingly high productivity. Ron summarizes the history of this type of solar-driven aquaculture; then the fish culture techniques, chemistry and energetics are described by Ron, John and David.

Concluding the section is a fantasy by John Todd, whose track record of transforming fantasy into reality is hard to surpass. He shows how many of the ideas that we have developed at New Alchemy could be integrated into a very small-scale but profitable homesteading scheme. It is a comfortably homey vision with considerable biological sophisticcation that comes together as something like an aquatic "Have-More" plan.

NJT



Where Have All the Fishes Gone?

John Todd

Last winter a sign was posted on the door of a local Cape Cod fish market. It said: "Temporarily closed due to high prices and lack of fish." The store is supplied by local fishermen and is independent of distant supply networks. Being close to the source, and near one of the country's greatest fishing grounds, it should have been less vulnerable than most fish markets.

Several months later, the price of young, live eels mysteriously and rather ominously shot up to $1,000 a pound. Young eels were being flown to Japan where aquaculturists raise them to edible size. They were being transported half-way around the world to a seemingly insatiable market. Ironically, several months later, the price dropped when the Japanese concluded that North American eels didn't taste as good as their own. However, with eels in short supply, I am betting that they will come to appreciate the taste of our eels. I was told that the atmosphere associated with the fishery on this coast was sinister and not unlike the drug trade where the stakes are high. Valuable and rare commodities, including eels, attract the underworld.

Cape Cod is named in honor of a fish which has been a traditional mainstay of New England's economy. The cod is under pressure too; recently an inshore dragger captain with a substantial vessel was quoted in the local press. He complained one bitter January morning: "Four passes, four damn passes in the snow. And what did I get for it? Not four-hundred fish . . . not forty. But four lousy fish, and small too, not even enough for supper." I had thought that his problem was that he specialized in such a sought-after species, but I was probably wrong.

I have a friend, Bryce Butler, who is writing a book on a subject dear to his heart and nearer to his stomach, entitled *The Trash Fish Cookbook* which he is co-authoring with Bill McLarney. The first installment of their book has already appeared in *The Book of The New Alchemists* (E. P. Dutton Press, New York). Lately, Bryce has been looking up fish brokers and various markets inquiring about trash fish. Old timers here would have one believe that half the ocean fishes caught in our waters are inedible and only fit to be thrown back into the sea. There is a snobbery tied to

what one eats and does not eat, or so the local myth goes. It was the little used and unappreciated fish that were the objects of my friend's quest; but he was told by fish buyers, in no uncertain terms, that there are no trash fish any more. The term is obsolete. All fish command high prices. The wolf fish, a big strange-looking blenny, is being used in the fish-and-chips trade, and I understand that they are good indeed. Even one of the most grotesque-looking fish in God's creation, the goosefish, has become a fish of commerce these days. My friend was much saddened by this news. It's harder to write about trash-fish cooking if there are no trash fish.

For some reason I don't fully understand, old notions die hard. It usually takes years, or even decades, for a new reality to catch up with events. There is a boom in fishing-boat building these days that has been fueled by the optimism created by the two-hundred-mile fishing limit. Every issue of my favorite newspaper, *The National Fisherman,* has page after page describing bigger and faster ocean-going vessels being built in places like Coos Bay, Oregon; New Bedford, Massachusetts; and Mobile, Alabama. These boats are getting more expensive—costing up to $7–8 million—and they are getting more efficient at gathering up what remains in the sea. The hunt is on. The only force that might keep the oceanic hounds at bay, and save the fish stocks, is the rising cost of fuel. Fishermen with financial investments as large as these are going to find ways around any regulations that might be set up to curtail their activities. Their only alternative to bankruptcy may well be evasion of the law. Further, the crisis, and I don't think this is too strong a word for what I am describing, is not just confined to North America. It is worldwide.

Just over a year ago, when I was traveling in southern Europe, the danger signs were unmistakable. In southern France ocean fish were in very short supply and their prices in market towns like Aix-en-Provence were far higher than beef, lamb or pork. The only reasonably priced fish served in restaurants were trout, which incidentally were superbly cooked.

In Italy, particularly in Rome, the situation was even more grave. One particular evening we were positively lusting after Italian fish cooking, and as good luck would have it we spied a small restaurant in a narrow, out-of-the-way alley which served fish exclusively. The smells emanating from the place were incredible. Waiting in line to be seated I watched a couple eating a modest-looking fish followed by salad and wine and coffee for dessert. As they paid their bill I peered over their shoulders to find out how much it was. I was stunned. Their meal had cost them the equivalent of $75. With profound culinary regrets, I fled to take refuge in pasta elsewhere.

The fisheries of the Greek islands are severely reduced. The inshore waters seem picked over. Wading in tidepools, I found little in the way of animal life beyond the odd sea urchin and the rare, small fish darting about amongst thé rocks. Considering the size of the vessels and the manpower in the fishing fleet, the return on their investment must be slight. One captain we befriended financed his vessel through taking tourists to out-of-the-way places for respectable prices. His livelihood as a fisherman had become almost a ritualized hobby and the odd fish that he caught were a cause for celebration.

My wanderings have turned up very little good news. Even the tropics of the New World are heavily fished. Near the New Alchemy farm on the Atlantic coast of Costa Rica, on good days the best reef fishermen catch only a few pounds of saleable fish, and the coveted lobster is in short supply. Although Venezuela would appear to be a particularly favored country with a long coastline and major rivers, including the Orinoco, that transect it, a former student of mine, Stewart Jacobson, now studying the African killer bees there, wrote recently that it was difficult for him to learn much about edible species of fishes because there were so few around to learn about. He did say that red snapper was becoming scarce in the local markets and cost considerably more than filet mignon in the most expensive supermarkets. The famed bagre, or river catfish, didn't appear in his city's fish markets as in earlier times. And so the story goes.

It would seem logical to conclude that world fish shortages would have catalyzed aquaculture into action to fill the yawning gaps left by the depletion of wild stocks. I don't think that aquaculture has yet responded to the challenge or to the need. And, with only a few notable exceptions, there may well be a comparable shortage of cultured species. I am basing this statement on the price and availability of young fish to fish farmers.

Several of my cohorts at New Alchemy and I have been making back-of-the-envelope calculations of fish-stock prices and in most instances we have found that young fish are scarce and costly. The absence of hatcheries and fish stock may be a real bottleneck in the development of aquaculture. Perhaps the easiest fish to breed and hybridize is the tilapia for they can be spawned in large aquaria. Yet, at the present, some breeders are getting as much as $200 per pound for young hybrids. Incidentally, all my calculations are based on batch lots of one-thousand fish. Non hybrid tilapia can be bought for as low a price as $12 per pound. Some of the hybrid sunfish cost half as much as hybrid tilapia or approximately $100 per pound. The white amur, or grass carp, seem to be a better bargain. Their breeding requires hormones and some real experience. The young are shipped at a larger size and they can be purchased for between $22 and $50 per pound. As far as we can tell, the best bargain in young fish is channel catfish which reflect the volume and the fairly sophisticated level of catfish culture. Young

channel cats cost $4–$5 per pound. In some parts of the country trout may be comparably priced.

These figures are not intended as absolutely accurate or up to date. They are rough estimates based on prices that we have paid in the past and the weights of fish received. They do not include shipping costs which are climbing quickly. However, shipping may still be a bargain provided the service is good.

These figures with their wide range of from $4 to $200 per pound for young fish, tell us that price and volume of cultured species are inversely related. This is certainly not news, but more easily bred fishes like tilapia should narrow the gap, which is not now the case. What is relevant and disturbing is the fact that many culturable species are in short supply. Hence the high prices and the scarcities. I am not faulting the fish breeders as they are not to blame. The underlying causes are in the structure of present-day aquaculture.

My purpose in all this is to alert the aquaculture community to the possibility of a worldwide, as well as a national, shortage of fish. These shortages extend into aquaculture. In the past, "trash" fish have been elevated to fill the gaps created by depleted fisheries and have saved the day for fishermen. These replacement fish, whether wolf fish or goosefish, are now legitimate, leaving precious few unexploited fisheries. Now the onus is on aquaculture, and it will have to see itself in a new light. A whole new generation of fish breeders, suppliers and growers are going to be needed and on a magnitude that we can hardly imagine. I have one suggestion. As a starter I propose that several of the lesser-known cultured fishes that feed low on food chains be farmed to replace ocean fishes in the large fish-and-chips market.

It would be a major task, but one well worth attempting.

Photo by Hilde Maingay

Peck's Milwaukee Sun 1877*

There are fish that should be propagated in the interest of the people. There is a species of fish that never looks at the clothes of the man who throws in the bait: a fish that takes whatever is thrown to it, and when once hold of the hook never tries to shake a friend, but submits to the inevitable, crosses its legs and says, "Now I lay me," and comes out on the bank and seems to enjoy being taken. It is a fish that is the friend of the poor, and one that will sacrifice itself in the interest of humanity. That is the fish that the State should adopt as its trade-mark, and cultivate friendly relations with, and stand by. We allude to the Bull-head.

The Bull-head never went back on a friend. To catch the Bull-head it is not necessary to tempt his appetite with porterhouse steak, or to display an expensive lot of fishing tackle. A pin-hook, a piece of liver and cistern pole, is all the capital required to catch a Bull-head. He lies upon the bottom of a stream or pond in the mud, thinking. There is no fish that does more thinking, or has a better head for grasping great questions, or chunks of liver, than the Bull-head. His brain is large, his heart beats for humanity, and if he can't get liver, a piece of tin tomato-can will make a meal for him. It is an interesting study to watch a boy catch a Bull-head. The boy knows where the Bull-head congregates, and when he throws in his hook it is dollars to buttons that "in the near future" he will get a bite.

The Bull-head is democratic in all its instincts. If the boy's shirt is sleeveless, his hat crownless, and his pantaloons a bottomless pit, the Bull-head will bite just as well as though the boy is dressed in purple and fine linen, with knee-breeches and plaid stockings. The Bull-head seems to be dozing—bulldozing, we might say—on the muddy bottom, and a stranger would say that he would not bite. But wait. There is a movement of his continuation, and his cow-catcher moves gently toward the piece of liver. He does not wait to smell of it, and canvass in his mind whether the liver is fresh. It makes no difference to him. He argues that here is a family out of meat. "My country calls, and I must go," says the Bull-head to himself, and he opens his mouth and the liver disappears.

It is not certain that the boy will think of his bait for half an hour, but the Bull-head is in no hurry. He lies in the mud and proceeds to digest the liver. He realizes that his days will not be long in the land, or water more properly speaking, and he argues that if he swallows the bait and digests it before the boy pulls him out, he will be just so much ahead. Finally the boy thinks of his bait, pulls it out, and the Bull-head is landed on the bank, and the boy cuts him open to get the hook out.

*Theodatus Garlick, M.D., 1877, quoting from "Peck's Milwaukee Sun" in Artificial Propagation of Fish, J. B. Savage Printer, Cleveland. 128 pp.

Some fish only take the bait gingerly, and are only caught around the selvage of the mouth, and they are comparatively easy to dislodge. Not so with the Bull-head. He says if liver is a good thing, you can't have too much of it, and it tastes good all the way down. The boy gets down on his knees to dissect the Bull-head, and get his hook, and it may be that the boy swears. It would not be astonishing, though he must feel, when he gets his hook out of the hidden recesses of the Bull-head, like the minister who took up a collection and didn't get a cent, though he expressed thanks at getting his hat back. There is one drawback to the Bull-head, and that is his horns.

Photo by Hilde Maingay

We doubt if a boy ever descended into the patent insides of a Bull-head, to mine for Limerick hooks, that did not, before the work was done, run a horn into his vital parts. But the boy seems to expect it, and the Bull-head enjoys it. We have seen a Bull-head lay on the bank and become dry, and to all appearances dead to all that was going on; and when a boy sat down on him, and got a horn in his elbow, and yelled murder, the Bull-head would grin from ear to ear, and wag his tail as though applauding for an *encore*.

The Bull-head never complains. We have seen a boy take a dull knife and proceed to follow a fish line down a Bull-head from his head to the end of his subsequent anatomy, and all the time there would be an expression of sweet peace on the countenance of the Bull-head, as though he enjoyed it. If we were preparing a picture representing "Resignation," for a chromo to give to subscribers, and wished to represent a scene of suffering in which the sufferer was light-hearted, seeming to recognize that all was for the best, we should take for the subject a Bull-head, with a boy searching with a knife for a long-lost fish hook.

The Bull-head is a fish that has no scales, but in lieu thereof has a fine India rubber skin, that is as far ahead of fiddle-string material for strength and durability as possible. The meat of the Bull-head is not as choice as that of the mackerel, but it fills up a stomach just as well, and *The Sun* insists that the Fish Commissioners shall drop the hatching of aristocratic fish, and give the Bull-heads a chance. There's millions in it.

Photo by Hilde Maingay

Cage Culture

Bill McLarney and Jeffrey Parkin

At last we have a cage-culture success story to offer those of you who want to grow fish for home consumption but have found that neither conventional aquaculture nor New Alchemy closed-system culture serves your needs. The rationale and basic techniques for cage culture were discussed in the fourth *Journal* (McLarney, 1977). At that time our case for cage culture would have been more convincing had we been able to back it up with impressive yields from the cages in Grassy Pond. But for two years we were embarrassed to have to report a failure to produce a respectable crop of caged fish (McLarney, 1977; McLarney and Parkin, 1978). Then in 1978 we managed to turn the tables, recoup our losses and come in with a bumper crop of bullheads.

While we are more inclined now to share our satisfaction than to dwell on previous failures, they must be recalled for long enough to explain what it was that made the difference. The major factor lay in the species selected for culture. Prior to our success with yellow bullheads (*Ictalurus natalis*), we had suffered disappointments with brown bullheads *(Ictalurus nebulosus)* and three sunfishes, the bluegill *(Lepomis macrochirus)*, the pumpkinseed *(Lepomis gibbosus)*, and a "hybrid bluegill" (♀bluegill x ♂green sunfish, *Lepomis cyanellus*). In 1978 we also conducted an unpromising, albeit perfunctory, trial with yellow perch *(Perca flavescens)*. I do not mean to imply that these fish are unsuitable in all cases. Francis Bezdek, of Aquatic Management, Inc., in Lisbon, Ohio, who was kind enough to donate

some of his hybrid bluegills to us, has had considerable success with them. However, he advised us that the only really effective feed he has found for them is minced trash fish, which is not practical for us to supply in quantity. Pure-strain bluegills have been successfully grown in cages at least once (Ligler, 1971).

We wish we could offer our readers some assurance that our experience of trial-and-error would save you the same. We cannot, but we submit that the yellow bullhead worked for us and so merits your serious consideration. We are, however, confirmed in our belief that cage culture, heretofore exploited in North America principally by commercial scale fish farmers, will eventually become a major method of raising protein for home consumption.

Our decision to work with yellow bullheads was actually made by default. We began the 1978 fish culture season by convincing ourselves the previous year's mass mortalities of brown bullheads were "flukes" (everyone knows you can hardly kill a bullhead) and that very careful handling would eliminate the problem of post-stocking mortality. It is doubtful that anyone could have been more solicitous than we in trapping, transporting and transferring our most recent batch of brown bullheads. But within a few days of stocking, the characteristic symptoms of loss of appetite, blotches on the skin and disequilibrium set in, both in the cages and in other tanks and ponds on the farm. Almost immediately, we suffered almost total mortality of captive brown bullheads at several locations. All the while, brown bullheads were thriving in the wild in Grassy Pond. As if to rub salt in our wounds, they would congregate around the cages, seeking scraps of feed.

Brown and yellow bullheads are indistinguishable to the casual observer and virtually identical in size and table qualities. (See taxonomic section at the conclusion of this paper.) We initially chose the brown bullhead on the basis of convenience; it is much more common on Cape Cod than the otherwise widely distributed yellow bullhead. With the most recent die-off of brown bullheads, it was easier to convince ourselves that the difference of species mattered and that it might be worth the trouble to seek out and trap yellow bullheads. Bill McLarney had participated in behavioral research with yellow bullheads in Michigan, California, and Massachusetts, without observing undue mortality. And there were those empty cages in Grassy Pond . . .

Trapping a minimal supply of yellow bullheads turned out to involve a couple of all-night adventures. We nearly lost a great number when one of us fell asleep and failed to detect an oxygen problem. But by June 29, 1978, with a month of the growing season already spent watching brown bullheads die, we were able to begin feeding our newly acquired yellow bull-

Photo by R. D. Zweig

heads in the cages in Grassy Pond. Despite substandard handling and a skeptical attitude on our part, the yellow bullheads thrived; only seven of the 214 fish (3.3%) died during the four months of the experiment.

Our original plan had been to stock four 1.2 m x 1.2 m x 0.9 m (4 ft x 4 ft x 3 ft) cages at 516, 367, 219 and 74 bullheads per cubic meter (14.6, 10.4, 6.2 and 2.1 per cubic foot respectively). However, the relative scarcity of small yellow bullheads that late in the season led us to cut down the number of cages to three, and to divide these cages into two halves with a Vexar® mesh partition. In an effort to maximize the amount of obtainable information, one half of each cage was stocked with sunfish, the total consisting of approximately 80% hybrid bluegills, 15% bluegills, and 5% pumpkinseeds, some of which had been held over from the previous year. These fish were fed a diet of Purina Trout Chow®, flying insects, which were captured using ultraviolet bug-light traps, and cultured midge larvae. Unlike the results with the yellow bullheads, the yields of the sunfishes were no more encouraging than in previous years and merit neither further remarks nor data analysis.

The other half of each cage was stocked with 100, 70 and 39 bullheads, or 148, 102 and 56 bullheads per cubic meter (4.2, 2.9 and 1.6 per cubic foot respectively). Since our initial expectations and our stock of yellow bullheads were similarly limited, we confined ourselves to gathering baseline data by feeding with Purina Trout Chow® in 1978, although we are still convinced of the shortcomings of commercial fish feeds as outlined in the fourth *Journal* and continue to work toward their total or partial replacement with a diet that is cheaper and more appropriate ecologically. Initially the bullheads were fed at a rate of 3% of total

body weight of fish, six days a week. The amount was recalculated every two weeks on the basis of sample weighing consisting of 1/3 of the fish in each cage. At times during the study, particularly in the final month, the bullheads would not consume that much feed. We attempted to reduce the rate of feeding at such times, but some feed was wasted. The bullheads were harvested November 3; results are shown in Table 1.

As can be seen from Table 3, during the period from October 6 to November 3, the bullheads in two of the three cages lost weight. Water temperatures in the cages during this period remained mostly between 4° and 16°C. (~ 40° and ~ 60°F.). The lowest temperature recorded between June 29 and October 6 was 15°C. (59°F.) We conclude provisionally that the minimum temperature for practical culture of yellow bullheads is to be around 16°C. (~ 60°F.). According to our estimates, had we harvested on October 6, the results shown in Table 2 would have been obtained.

Based on estimated production as of October 6, we calculate the monetary cost of cage culture of yellow bullheads in our most productive cage (Cage 1) as follows:

Cage Materials (Vexar® mesh, wood, paint, styrofoam, nylon cord)	$35.46
Feed	$11.88
Total Weight of Bullheads Produced	10.66 kg (23.5 lb)
Cost Per Unit Weight	$ 1.45 kg ($0.66 lb)

The preceding cost per unit weight figures reflect one half of the cost of cage materials, as only one half of each cage was stocked with the bullheads, with an amortization period of five years.

The labor involved, apart from biweekly sampling, which would not be necessary in a production system, and cage construction came to less than one-half hour a day, adding a full day at stocking and harvest time. Labor time could be less under other circumstances; to reach Grassy Pond from our offices necessitates a quarter-mile walk and a short boat ride. Many growers could keep cages virtually in their back yards. The initial cost of acquiring the bullheads is not included as they are easily trapped and transportation costs would be variable.

As discussed later in this article, we anticipate reducing the production costs. Even now it is interesting to compare the cost of cage-cultured bullheads with that of other animal protein foods. Commercial growers of channel catfish *(Ictalurus punctatus)* in the lower Mississippi Valley report similar or slightly lower costs over a twelve-month culture period. From informal interviews with New Alchemy visitors who grow trout on a small scale, I estimate that in New England it presently costs around $3.33 to produce a kilogram ($1.50/lb) of rainbow trout *(Salmo gairdneri)*; large-scale commercial trout farmers do much better—about $1.44/kg ($0.65/lb). Chicken can be produced commercially at about $0.99/kg ($0.45/lb) for straight-run broilers using conventional methods. I leave it to the reader to compare the cost of cage-cultured bullheads to animal protein purchased from retail markets.

Those wishing to attempt cage culture can read the basics in the fourth *Journal*. Armed with the information found there and that presented here, you could then consider suggestions arising from our experience for improving on our results.

The most obvious tactic for improvement for us involves timing and rate of stocking. We should stock our cages as soon as water temperatures are suitable for growth, probably sometime in May. And we should stock cages entirely with bullheads, eliminating the sunfish for the time being. It is perhaps less obvious that it should be feasible to stock our cages much more densely. The rates used in 1978 are lower than those used by commercial channel-catfish culturists, and were chosen only because of our shortage of stock. If

TABLE 1 Results of cage culture of yellow bullheads (Ictalurus natalis) *in Grassy Pond, Hatchville, Massachusetts, June 29—November 3, 1978.*

Cage No.	*No. Fish Stocked*	*Total Initial Weight kg (lb)*	*Mean Initial Weight kg (lb)*	*Total Final Weight kg (lb)*	*Mean Final Weight kg (lb)*	*Production Per Volume kg (lb) m^3 (ft^3)*	*Conversion of Feed*
1	100	5.5 (12.1)	0.054 (0.12)	15.7 (34.7)	0.16 (0.35)	15.1 (0.94)	2.52
2	39	2.0 (4.5)	0.054 (0.12)	5.8 (12.8)	0.15 (0.34)	5.6 (0.35)	2.57
3	70	3.9 (8.5)	0.054 (0.12)	11.0 (24.2)	0.16 (0.35)	10.4 (0.65)	2.24

TABLE 2—Results of cage culture of yellow bullheads (Ictalurus natalis) *in Grassy Pond, Hatchville, Massachusetts, June 29—October 6, 1978.*

Cage No.	*No. Fish Stocked*	*Total Initial Weight kg (lb)*	*Mean Initial Weight kg (lb)*	*Total Final Weight kg (lb)*	*Mean Final Weight kg.(lb)*	*Production Per Volume kg (lb) m^3 (ft^3)*	*Conversion of Feed*
1	100	5.5 (12.1)	0.054 (0.12)	16.1 (35.6)	0.16 (0.36)	15.7 (0.98)	2.11
2	39	2.0 (4.5)	0.054 (0.12)	5.2 (11.5)	0.14 (0.30)	4.6 (0.29)	2.67
3	70	3.9 (8.5)	0.054 (0.12)	10.7 (23.5)	0.15 (0.34)	10.1 (0.63)	2.03

TABLE 3 Stocking, growth rates and incidence of injury and mortality in three lots of cage-cultured yellow bullheads (Ictalurus natalis) *in Grassy Pond, Hatchville, Massachusetts, June 29–October 6, 1978.*

Cage No.	*Stocking Rate (Fish Per Cubic Meter)*	*Percent Growth*	*Percent of Fish Scarred or Injured From Fighting**	*Percent Mortality*
1	148	194.7	4.0	1.0
2	56	154.9	31.6	7.5
3	102	176.0	20.3	4.3

* These observations were actually made on November 3. From what we know of bullhead metabolism, these percentages would have very likely been higher on October 6.

channel catfish will survive and grow at 300 per cubic meter (8.5 per cubic foot) (Collins, 1978), it is reasonable to assume that yellow bullheads, generally a hardier fish, will do well at the same, and perhaps at higher, densities. More surprising, there is reason to believe that, not only is total production in cages likely to increase with denser stocking, up to an as yet unknown safe upper limit, but the growth rate of individual fish may actually improve at higher densities. This is the opposite of what one would logically expect, but our 1978 data suggest such a trend (Table 3).

As it happens, the theoretical framework for explaining the seemingly illogical trends suggested by Table 3 was provided by the research of John Todd and his colleagues at the University of Michigan in the sixties. Summarizing briefly the tale told by John in *Scientific American* (Todd, 1971); at low population densities, yellow bullheads are ordinarily solitary. Each adult defends a well-defined territory. Such conflicts as occur are between individuals and are mostly ritualized, and physical injury of one fish by another is rare. When bullhead populations exceed the level at which all territories are occupied, fighting will break out and injuries, even mortality, may ensue. But at still higher population densities, territoriality is "abolished" and neither ritual defense nor fighting occur. Mortality, injury, and diversion of growth energy into aggressive behavior affect the growth of individual fish and the productivity of fish culture systems adversely. If population density high enough to eliminate aggressive behavior can be maintained without creating pollution problems in the system, it follows that growth and production might be enhanced. As explained in the fourth *Journal*, cage culture is uniquely suited to exploit this potential.

Yet another area in which we hope to effect improvement is feeding. We may or may not be able to improve the rate of bullhead growth by modifying feeding methods, but we are confident that we can lower costs and improve the conversion of commercial feed. Table 3 shows that the growth rate of our bullheads varied greatly from one two-week period to the next. Insofar as this apparent variation reflects a real difference and not merely sampling error, we should inquire into the sources of variation. Some may be due to differences in the efficiency with which the fish converted the food they consumed. We are of the opinion though that the variable growth rate is primarily a reflection of the percentage of the offered feed that was actually eaten. At certain times considerable quantities of uneaten feed had to be removed from the cages. Significant reduction of wastage will almost inevitably come about as we gain familiarity with the species and sharpen our judgment as to when to cut back or intensify feeding. As a result, over a period of time, we will be able to formulate guidelines for correlating feeding rate with water temperature, as temperature was certainly the main causative factor in the near cessation of feeding that was reflected in the poor growth obtained during the period October 6–November 3. While we did not adjust the feeding rate for temperature this year, we did begin to gather information necessary to do so.

It is also possible that alteration of the daily feeding schedule would improve our results. Research at the Milwaukee Public Aquarium (Spieler, 1977) suggested that, even though goldfish *(Carassius auratus)* will feed at any time of day, conversion of feed is markedly better at certain times and not others. Applying this information to bullheads, which are largely nocturnal, it seems not unlikely that nocturnal feeding would result in improved growth. Nocturnal feeding would be problematical for us logistically, but some home growers, for whom feeding might involve no more than walking out to the end of a dock, might find it convenient.

We are considering trying to accomplish the same end through use of "demand" feeders. Demand feeders are devices loaded with feed, suspended over the water. Fish learn to depress a lever which results in the release of feed. So far we have been disinclined to use demand feeders, because they tend to reduce the amount of contact between fish and farmer, and they are reported to encourage excess consumption of feed. However, they would almost certainly reduce wastage, and it may be that, given the extreme and so far unpredictable variability in our bullheads' appetite, it would be beneficial.

Even without wastage, the major factor in the production cost of our bullheads would have been feed. In American aquaculture as a whole, the single most costly production item is fish food, accounting for 25% to 80% of total costs, depending upon the efficiency and type of operation (Greenwalt, 1978). This is one reason for our long-range goal to develop alternative feeds for the fishes we grow. At New Alchemy we have available at least five sources of feed that may be applied in future research on cage culture of bullheads:

1. cultured earthworms;
2. cultured midge larvae, which have already been shown to have a growth-promoting effect in tilapia diets (McLarney, Levine and Sherman, 1976; 1977);

3. flying insects captured with U-V bug lights;
4. occasional supplies of fish entrails from the cleaning of other cultured and wild-caught fish; and
5. small cyprinids which gather around the bullhead cages at feeding time. On seeing these fish, John Todd suggested that they could be captured periodically with some device like an umbrella net, and placed in the cages. In nature bullheads are not very effective in capturing small fish, but in a small enclosure, after dark, they will run them down.

None of these feeds, with the possible exception of the earthworms, are available at the present in quantities adequate for use as the sole food of cage-cultured fish. Nor would any in itself be likely to provide as well balanced a diet as commercial feed. However, it is possible that supplementing a commercial diet with any of them might result in improved growth and/or conversion. And, since all the alternate feeds are extremely low in cost compared to commercial feeds, replacement of even a portion of the commercial diet with such feeds would result in significant savings.

A final, simpler improvement involves covering the cages. In 1978, one half of each cage was covered with black plastic, so that both bullheads and sunfish had access to open and shaded areas. The bullheads spent almost all their time in the shaded part. Given this indicated preference and the fact that channel catfish have been shown to grow better in cages with opaque covers than in uncovered cages, we plan to provide full covers for our bullhead cages in 1979.

Another planned modification is a 50% reduction in cage size, from 1.3 to 0.65 cubic meters (48 to 24 cubic feet). This is not expected to affect production per unit volume, but will permit us to gather more data without cluttering up Grassy Pond. Since yellow bullheads in 1978 grew well in a half of a 1.3 cubic meter cage, we see no reason why they should not do so in a cage one-half that size. Our new 1.2 m x 0.6 m x 0.9 m (4 ft x 2 ft x 3 ft) cages will be smaller, particularly in surface area, than the smallest cages mentioned in the cage-culture literature (0.9 m x 0.9 m x 0.9 m). Cages of this size, assuming they prove as effective as we hope, might be advantageous for some small-scale growers.

We have gone into some detail about our plans, not because we are dissatisfied with our 1978 results—we think our cost and production figures speak well for New Alchemy cage culture—but because we wish to involve our readers in the ongoing experiment. North American homestead cage culture today is about at the point gardening was when someone brought in the first lettuce crop and shared it with the neighbors. We look for many exciting developments in the years to come and hope that by sharing, not only our successes but some of our problems and untried ideas, we will accelerate the rate of progress.

Let us return to hard fact to conclude this treatise; the particular hard fact at hand being that bullheads are delicious. This assertion has been made in these pages before (McLarney and Butler, 1976; McLarney, 1977) but November 3, 1978, marked the first time we had enough bullheads on hand to prove it to any New Alchemist and/or local friend still in doubt. A portion of the crop was fried for the first annual New Alchemy bullhead feast. And, based on the discriminating and satisfied smacking witnessed by the partakers, it appears the bullhead has few rivals in texture and taste.

A NOTE ON BULLHEAD TAXONOMY

The American Fisheries Society's "A List of Common and Scientific Names of Fishes from the United States and Canada" lists eleven species in the catfish genus *Ictalurus*. Six of them, formerly classified in their own genus, *Ameiurus*, bear the common name of "bullhead." Of the remainder, two are obscure species of limited distribution, while three (the channel catfish, *Ictalurus punctatus*, the blue catfish, *Ictalurus furcatus;* and the white catfish, *Ictalurus catus*) are large species of commercial importance to fisheries and aquaculture. No matter that the taxonomists have "lumped" the bullheads together with the larger *Ictalurus* spp., they differ from the channel, blue, and white catfishes in two characteristics of importance to small-scale aquaculturists. In the first place they are smaller. Most of the bullheads taken by anglers weigh less than a pound. Secondly, their delicious red flesh is very different in appearance and flavor from that of the larger *Ictalurus* spp. The bullheads are supposedly hardier than the other *Ictalurus* spp., but our experience with brown bullheads weakens that generalization.

Our experience with brown and yellow bullheads does indicate the importance of knowing which species of catfish you are working with—hence these paragraphs. The inexperienced aquaculturists may not know how to distinguish bullheads from small channel, blue, or white catfishes; it is a simple enough matter. The larger catfishes have *forked* tails, whereas bullhead tails are rounded or straight edged.

Distinguishing between bullhead species is another matter. The three widely distributed bullhead species—the brown bullhead *(Ictalurus nebulosus)*, the yellow bullhead *(Ictalurus natalis)*, and the black bullhead *(Ictalurus melas)* are extremely similar in appearance. Before offering our assistance in bullhead identification, let me suggest that you not rely on the word of fishermen or fish farmers, who rarely know which species they have. Nor are the common names of any use, so great is regional and environmental variation in bullhead coloration. On Cape Cod the rule we facetiously cite is "brown bullheads look yellow, but yellow bullheads appear brown."

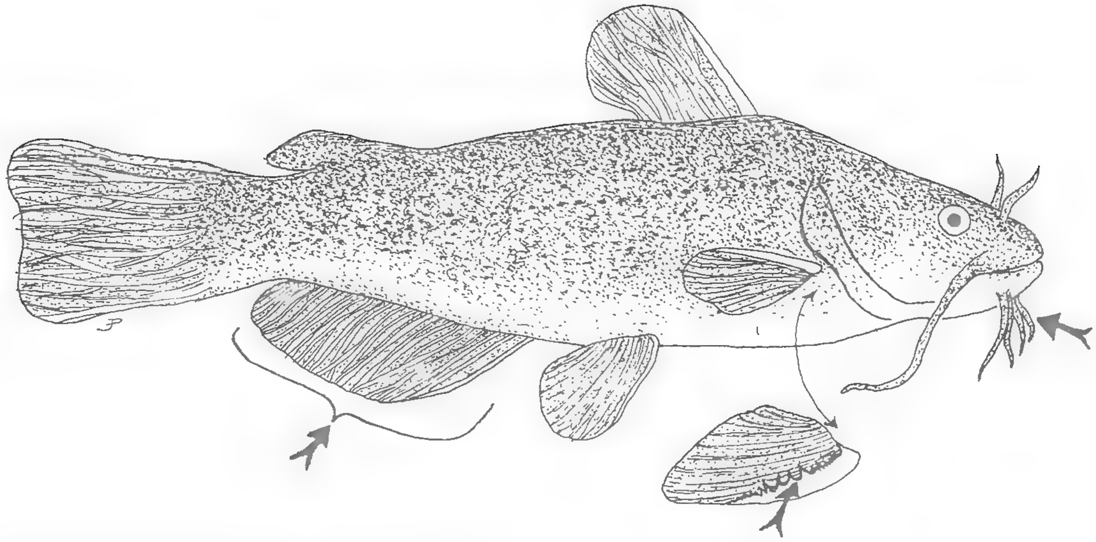


Figure 4. *Brown bullhead* (Ictalurus nebulosus) *showing portions of the external anatomy of most importance in species identification of bullheads.*

The characteristics of most use in identifying bullheads are:

1. pigmentation of the chin barbels,
2. the length of the anal fin, and
3. the degree of serration on the posterior edge of the pectoral spine.

Location of these characteristics is illustrated in Figure 4; their use in species identification is outlined in Table 4.

An additional characteristic we find useful on Cape Cod is stridulation which is a "croaking" sound produced by movement of the pectoral fin in its socket. We note that brown bullheads often stridulate when handled, whereas yellow bullheads never do. It is not known whether this trait would be diagnostic elsewhere.

The fourth bullhead species, the flat bullhead (*Ictalurus platycephalus*), is unknown to us, but the literature suggests that it should be relatively easily distinguished from the other bullheads, by virtue of its flattened head and more slender profile, but especially by a large black spot at the base of the dorsal fin. Its distribution is apparently limited to the Carolinas, Georgia, and Florida.

The other bullheads are widely distributed in the United States, southern Canada, and northern Mexico. Various texts offer distribution maps for the three species. However, there are so many exceptions to the available distribution information as to render these maps virtually useless as aids to identification. The fact is that not only most fishermen, but even a good many fishery biologists, do not bother to distinguish among the bullhead species, and so they have all been introduced, willy-nilly, everywhere. As our experience demonstrates, bullhead taxonomy is important, and we urge all of you who are even considering working with bullheads to familiarize yourself with it and in cases of doubtful identity to consult competent authorities.

TABLE 4—Distinguishing Characteristics of the Three Principal Bullhead Species.

Species	*Chin Barbel Pigmentation*	*Length of Anal Fin*	*Serrations on Posterior Edge of Pectoral Spine*
Ictalurus natalis, yellow bullhead	None (barbels whitish or yellowish)	Long (23–28 rays)	Small, but distinct
Ictalurus nebulosus, brown bullhead	Black, dark brown or with dark spots, at least on the base	Medium (22–24 rays)	Stout (If you grasp the spine between thumb and forefinger and attempt to stroke from the base toward the tip, the serrations will catch the skin.)
Ictalurus melas, black bullhead	Like *I. nebulosus*	Short (16–22 rays)	Spine smooth or little serrations

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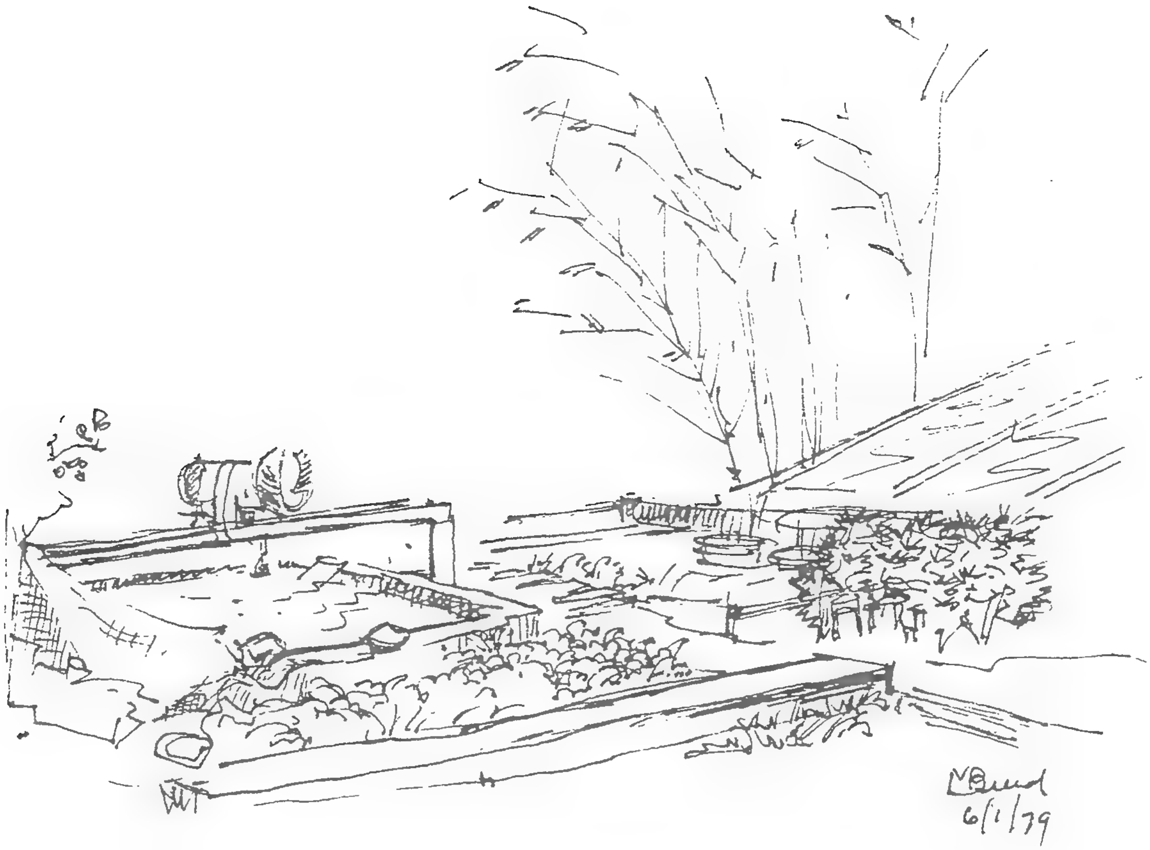
Photo by R. D. Zweig



Biological Filters, Water Quality and Fresh Water Clams

Michael Stewart Connor

There is an old vaudeville joke about a man one night encountering a drunk crawling under a streetlight. When asked what he was doing, the drunk replied, "Looking for a penny I dropped." The man bent down and helped search for awhile before he asked, "Just exactly where did you drop it?" The drunk pointed to a spot twenty yards away. "Well, then, why are you looking for it way over here?" "Because the light's better here!"

Much the same story could be told about biological filters for closed-system aquaculture. Filters were first built for the aquarium industry, and most aquaculture filters are simply extrapolations from those. Yet it should be obvious that the needs of an aquarist for keeping a few exotic fish alive in a sterile medium differ radically from those of an aquaculturist trying to maximize productivity at the least cost energetically and economically.

How does a fish affect the quality of the water in which it lives? Most obviously it reduces oxygen levels and increases the amount of carbon dioxide in the water. Also it excretes ammonium ions and organic wastes that are high in nitrogen, the decomposition of which can lower oxygen levels. Ammonia was long ago shown to be toxic to fish, and water filters were developed that catalyzed the microbial transformation of ammonium to nitrate. These filters are basically tubes containing lots of surface area—cracked oyster shells are a popular substrate—and perhaps some sort of agitation to get more air into the water. Most filters also screen out phytoplankton, which are sometimes considered a nuisance because massive phytoplankton die-offs can seriously deplete the water of oxygen. The effectiveness of such filters has been judged by how well they convert ammonium to nitrate, not how well they allow fish to grow.

A water filter that converts ammonium to nitrate and removes phytoplankton has little relevance to our

desire to improve fish growth in solar-algae ponds. Ammonium is removed from the water by phytoplankton to levels far below those the fish can discern. Yet the phytoplankton themselves are a resource. They oxygenate the water during the day. In addition they are a nutritious source of food for herbivorous tilapia. New Alchemy has found repeatedly that solar-algae ponds without filters grow fish just as well as those with filters, with ammonia levels low in both instances.

Unfortunately, dismissing ammonia toxicity does not solve all water quality problems. Besides excreting organic wastes which may foul the water and scavenge oxygen, fish also release into the water chemicals that can cause significant behavioral and growth effects. John Todd has written extensively about chemicals that cause passivity and aggression in catfish. Little is known about the ecological effects of these chemicals in natural systems, about either their residence times or how they are removed from the water. There is a growing amount of evidence that animals, such as fresh water clams or mussels, that could remove dissolved organics by filtration increase fish growth.

Experiments at Auburn University by H. S. Swingle showed that fresh water mussels can increase the carrying capacity of largemouth bass–bluegill sunfish ponds. For five years the average standing stock of fish in a pond containing mussels *(Lampsilis clairbornensis)* was 1½ times greater than the control ponds. Swingle felt the difference in fish production was a function of the filtering action of the 40,000 mussels on the two-acre pond bottom. The filtering net of a mussel has a large absorptive surface that can remove dissolved organic compounds and improve water clarity.

Similar results were found in growing catfish in 170 liter tanks at the Fish Farming Experiment Station (Stuttgart, Arkansas) where James Ellis and Dewey Tackett compared the filtering effect of using 30 mussels (*Anodonta* spp.) instead of regular water filters. Catfish in the aquaria containing mussels grew 1½ times as fast as those without mussels. There was no significant difference in water quality parameters in the tanks.

Such results seem generalizable to a great variety of fish-mussel combinations. Over the past year I have experimented with local fresh water and salt water species. The fish and mussels were placed in 15 gallon aerated aquaria and fed Purina Trout Chow®. One combination used our local fresh water mussel *Elliptio complanata*, common throughout the Northeast, and bluegill sunfish. The other experiment used a local marsh minnow, *Fundulus heteroclitus*, and the horse mussel, *Modiolus demissus*, and switched aquaria halfway through the experiment. In all cases fish grew faster in aquaria containing mussels. These differences were significant at $P < .05$ in only a few cases because of the small sample sizes (Table 1).

For the most part fresh water clams and mussels have been ignored in this country. They have little commercial importance. We usually associate them with a muddy taste, but this need not be so. Most mussels are quite tasty once they have been transferred to phytoplankton-rich water for a week.

Some fresh water clams are sold here, for instance smoked *Corbicula* at about one inch in width. Introduced to this country from China, *Corbicula* is considered a nuisance in the United States because it clogs irrigation canals and intake pipes. But in Asia, particularly Taiwan where 5,000 acres are used for *Corbicula* culture, it is eaten as a delicacy as well as for its medicinal value in the treatment of liver disease. The Taiwanese commonly raise them in polyculture systems with bighead, silver and grass carps. Clam growth-rate depends on size, local environment and the amount of food available. Growth ranges from 0.7–3% wet weight/day with an average of about 1½%, fast enough to harvest them after one growing season.

TABLE 1A—The effect of fresh water mussels (Elliptio complanata) *on the growth of bluegill sunfish.*

Growth of Eight Sunfish (% day + S.E.)	*No Mussels*	*Ten Mussels (Avg. Wt. 80 g)*
After 15 days	.47 ± .12	.50 ± .08
After 27 days	.10 ± .08	.21 ± .09

TABLE 1B Growth of Fundulus *in aquaria containing different densities of mussels.*

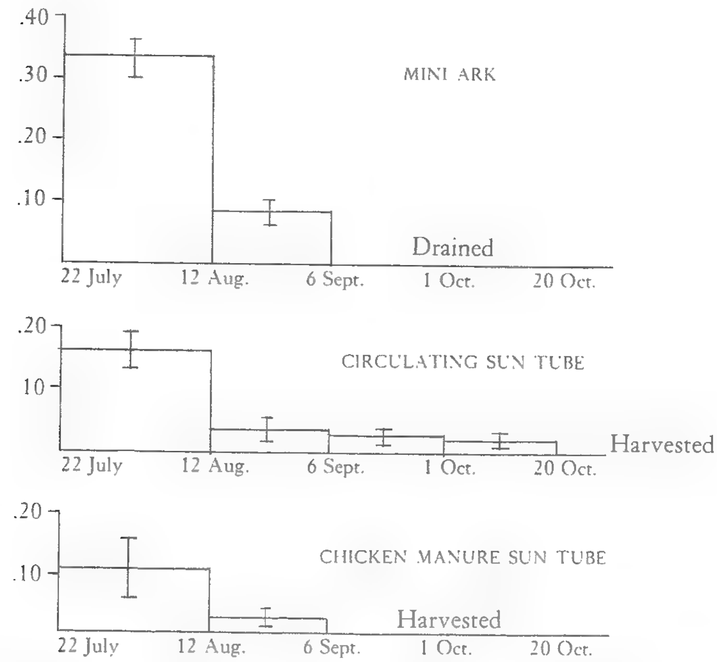
Growth (% day) (+S.E. of Ten Fish)	*Mussel Density (Number per 15 l aquarium)* 0	2	6
After 15 days	.96 ± .10	.92 ± .11	1.07 + .10
After 29 days	.24 ± .055	.34 ± .058	.40 ± .049**
Aquaria switched			
After 15 days	.02 ± .065	.21 + .062*	

*S.E = Standard error
**Significantly different ($P < .05$) from zero mussels Mann-Whitney-Wilcoxon U-test.

In the summer of 1978, Ray Dinges sent us some *Corbicula* that he had collected in Texas. Ray sent the clams air-freight in a styrofoam cooler with several moist sponges on top. The clams spent a day sightseeing in a LaGuardia terminal due to an airline mix-up. Even so, when we received them only a small percent were dead, a remarkable display of hardiness.

While waiting to use the clams in experiments, we divided them among several solar-algae ponds and a lab aquarium. During a failure of one of the solar-algae pond aerators, we learned an important difference between clams and fish, namely, that clams do not swim. When oxygen reached dangerously low levels in a tank bottom, the *Corbicula* have no recourse but to

TABLE 2—Growth of Corbicula *in Three Different Environments*



clam up. Once a few clams have died, oxygen levels are reduced further and mass mortality can result.

Subsequently, we made little purses for the clams from Vexar® netting and suspended them near the surface of the tanks to improve the clams' access to oxygen. To follow the growth of individual clams, we marked each one by attaching small numbered labels and covering the label with Dekophane® (Rona Pearl Corp., Bayonne, New Jersey), a non-toxic, quick-drying glue. Most of the labels remained legible for about three weeks.

We placed Vexar® purses each containing 20 clams in two of the "Champagne Race" solar-algae ponds and in the upper pool of the mini-Ark. Unlike that of the solar ponds, the mini-Ark water flowed constantly and remained clear. Phytoplankton growth was dense in both solar ponds reducing water visibility to a few inches. One solar pond was a continually flowing, siphoning system that received some supplementary feed. The other received only chicken manure. Both were aerated.

It took a few weeks for the solar-algae ponds to become buffered. Initially, pH values fluctuated by three or four units during the day. During this acclimatization period, nearly a third of the clams died in both solar ponds. After that, survival was better. All of the clams in the mini-Ark were healthy and grew at about half the rate of clams of the same size in Taiwan and quite a bit faster than those in either of the solar ponds (Table 2). In all the habitats growth slowed considerably over time. This was probably a function of declining temperatures. *Corbicula* prefers warm water which should make it an ideal component of the solar-algae ponds.

Beyond the decline in growth rate, we were disappointed that we did not get any of the clams to spawn, a process that occurs frequently in Ray Dinges' ponds. Nevertheless, initial results encouraged us about the potential of fresh-water clams in polyculture systems.

Clams have several benefits. They reduce algal density, speed nutrient cycling, and may remove fish growth inhibitors. They also produce large amounts of pseudofaeces, popularly known as mussel "mud." Initially the pseudofaeces probably represent large packages of food for the fish. After decomposition, mussel mud makes a superior vegetable fertilizer. Most importantly, the clam production itself can be used, either as food for humans or the fish —a claim that can be made by no other biological filter.

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Photo by Hilde Maingay

Solar Aquaculture

Historical Overview

Ron Zweig

Designs for aquatic ecosystems that optimize the entry of solar energy have the advantage of maximizing the potential for biological productivity. During the past three decades, significant research in aquatic biology has demonstrated that phytoplankton are the organisms that use solar energy most efficiently. The potential for algal culture in sewage and waste treatment (Lincoln, 1977), energy production (Oswald and Golueke, 1960; McLarney and Todd, 1972; Zweig, 1978), and food production (McLarney and Todd, 1972; Zweig, 1977, 1978) is being increasingly realized. At the New Alchemy Institute, many of the

characteristics of algae have been incorporated in solar aquaculture design.

The use of light-penetrating cylinders for the culture of algae has proved highly efficient. The earliest reported design (Cook, 1950) used a pyrex glass cylinder four inches in diameter and six feet in height for the culture of the phytoplankton, *Chlorella pyrenoidosa* Link. This flow-through, continuous-culture apparatus was tested both under laboratory conditions with artificial lighting, and outdoors with natural sunlight. The study determined that 5% of incident sunlight or 2.5% of the total solar radiation was converted to organic matter. The most favorable conversion in agriculture has been 0.3% of the total radiation of a year. Cook concluded that there was a great potential for solar-driven algal culture and that further study would help to realize its possibilities.

A literature survey (Tamiya, 1957) reviewed the mass culture of algae and compared several culture techniques. The work of Mayer et al. (1955) further supported the premise that the optimization of light improved productivity (gms. of algae/m^2/day). In a deep tank with transparent side walls, a closed (no exchange of water) culture of *Chlorella* that was stirred constantly proved to be the best system described, of both open and closed culture schemes.

In 1974 the New Alchemy Institute combined the idea of algal culture in transparent cylinders with that of raising protein-rich herbivorous fish (Todd, 1975, 1976, 1977; McLarney and Todd, 1977). The solar-algae ponds which are translucent fiberglass silos five feet in diameter and in height mark the most successful design to date (Zweig, 1977). These semi-closed aquatic ecosystems are used primarily for the culture of fishes as human foods.

A key factor in closed-system fish culture is the management of toxic fish wastes. The most critical compound that must be controlled is un-ionized ammonia. Concentrations as low as 0.12 ppm have been shown to inhibit channel catfish growth (Robinette, 1976). A beneficial aspect of a fish culture system that is algae-based is that some Chloroccocale, such as *Chlorella* and *Scenedesmus*, are capable of metabolizing ammonium directly, helping to eradicate the problem (Syrett, 1962).

In an undisturbed, subsurface pond there is a difficulty with intensive algal culture in that photosynthetic activity is limited to the upper layers (Oswald and Golueke, 1960). Oxygen concentrations are usually high at the surface and negligible in the lower regions of the pond. Periodic stirring of the ponds is required to prevent anaerobic conditions from developing. The advantage of an above-ground translucent cylinder is that light penetrates the entire column of water, making it capable of photosynthesis and reducing the chance of anaerobic conditions developing. Stirring is just needed nocturnally. In a fish culture system, fish species can be chosen that assist stirring through their swimming behavior.

The photosynthetic activity in the solar-algae ponds has significance beyond improved ozygenation of the water and toxic waste removal. In one study (McConnell, 1965), it was demonstrated that fish growth could be directly correlated to photosynthetic activity. A linear relationship was found to exist between photosynthesis and the cube root of the mass of growth per individual fish (*Tilapia mossambica*).

The most efficient strategy for the utilization of a three-dimensional volume of water was first developed in Chinese polyculture (Fan Lee, 5th century B.C.; Chen, 1934). In these designs, species of food fish that could exploit different trophic levels were used. They included plankton feeders and bottom and macrophytic plant feeders. This concept was integrated into solar greenhouse aquaculture design (McLarney and Todd, 1972) where the volume of water was also used for heat collection and storage. The fertile fish water was also used to irrigate the vegetables grown within the structure.

The polyculture strategy for the solar-algae ponds is based on the nature of fish feed organisms that grow within them and the supplementary feeds that can be introduced from outside. As for the choice of fish species, the best possibility is for planktivorous fish capable of utilizing the zooplankton and phytoplankton in the water column. For a tropical range of temperatures, species of tilapia are very efficient. The Sacramento River Blackfish, *Orthodon microlepidotus*, is useful when cooler temperatures prevail (Murphy, 1950). These species also insure the turnover of the phytoplankton population, preventing a senescent condition from developing. A species such as the Israeli carp, *Cyprinus carpio* var. *specularus*, capable of feces and sediment recycling, would be advantageous. The sessile organisms growing on the side walls and bottom are another potential nutrient source that could be grazed by any of these fish.

In an early fish-production experiment with the solar-algae ponds (Zweig, 1977), a polyculture strategy was used that included *Tilapia aurea*, Israeli carp, the Chinese bighead and silver carps. The tilapia comprised a majority of the population. During a 98-day trial, 2.5 kg. per cubic meter or 3.84 kg. of fish was produced per square meter surface area with an s conversion of 1.0. The results of the experiment proved this solar-energy-based aquaculture system to be nearly ten times more productive than any other described standing body of water (Zweig, 1977).

The aquaculture system has also proven viable economically, simply as a passive solar collector within greenhouse structures (Zweig, 1978). John Wolfe has calculated that over the 20-year period the ponds are expected to last, for every calorie used in the manufacture of the ponds, five calories of thermal energy can be

gained through passive solar collection in a climate comparable to that of the Cape. This calculation is based on the heating season for Cape Cod.

The demonstration of the potential of the solar-algae ponds at New Alchemy has stimulated other research. At the Ark Project on Prince Edward Island, the ponds are being used for heating and for trout culture. The ponds are linked together to form a recirculating "solar river" that includes a small hatchery operation expected to produce 50,000 fry per year. The Prince Edward Island Department of Fisheries has reported a ninefold increase in phytoplankton feeds for oysters (Campbell, personal communication). Experiments with solar-algae pond systems are also underway currently at Fordham University, Goddard College, and the University of California, Santa Barbara. Several other organizations and private individuals have been incorporating solar aquaculture in their greenhouse designs. At Sea Plantations, Inc., a commercial aquaculture enterprise in Salem, Massachusetts, translucent, fiberglass tanks are being used to culture marine phytoplankton as feed for clam production (Cornell, 1978).

The importance of and potential for the innovative utilization of solar energy is becoming increasingly evident. Spoehr wrote in 1951 that "vision is necessary, but the vision must be a disciplined and practicable one." The term "practicable" here could be interpreted to mean useful and resilient. "Disciplined" should not simply mean rigorous research but should imply as well that the application of the research be beneficial and sensitive to surrounding ecosystems.

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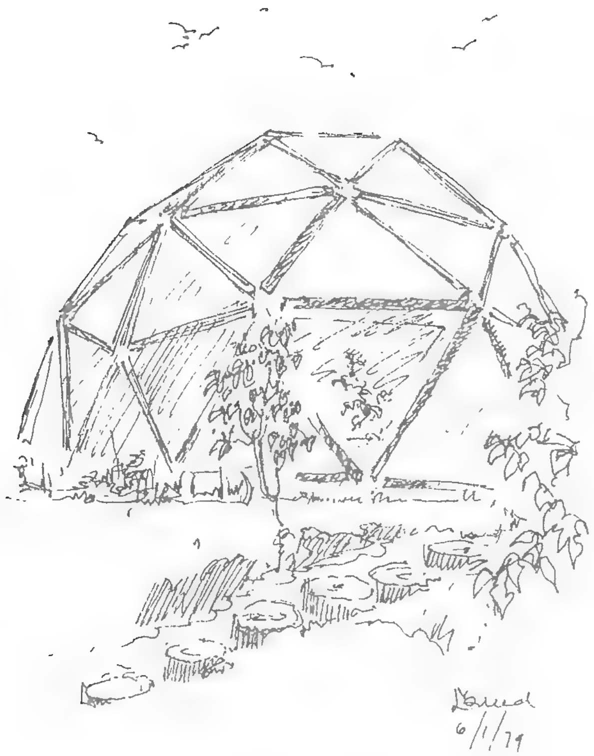


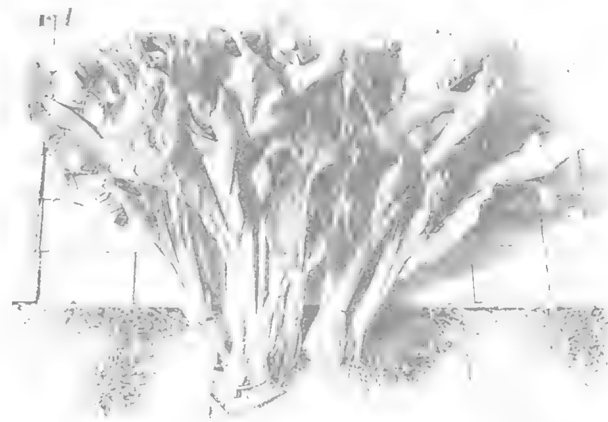
The Dome as Nursery

Ron Zweig

During the summer of 1978, the subsurface pond in the Dome was used as a breeding pool for tilapia, *Sarotheradon aureus*.[1] The purpose of such a monoculture was to provide fry for the experiments in the solar-algae ponds. Several thousand fry were taken from the pond. The project provided the means for quantitatively evaluating comfrey and Purina Trout Chow® as the predominant supplementary feeds for the fish.

In mid-May, 171 adult tilapia were put into the pond, which holds 19 cubic meters of water. On entry the fish weighed 8.34 kg. During the 182 days of production, they were fed a total of 20.0 kg. of commercial food and 108.4 kg. wet weight (9.64 kg. dry weight) of fresh comfrey, *Symphytum peregrinum*, which is high in protein and Vitamin B, bringing the total dry weight equivalent feed to 29.64 kg.[2] The amount of feed was over four times greater than that of the previous summer which was 6.97 kg.[3] We did this to assess the impact of increased feeding on fish growth and to try to increase the net productivity of the system. Phytoplankton populations during both trials appeared to be of equivalent density although neither cell counts nor species identifications were made.

On November 8, 1978, a total of 38.31 kg. of fish were retrieved from the pond, a net production of over 6.8 kg. higher than the previous growth trial in this pond.[4] This amounts to approximately 1.6 kg. per cubic meter of water or about 166 gm. of growth per day. It is important to note that conversion ratios for both the dry-weight comfrey and the commercial feed to wet fish produced was 0.98 or 0.67 for the commercial feed alone. To reduce the quantity of Purina Trout Chow, the potential of comfrey as the primary food in the diet with decreased amounts of high protein feeds will be explored in future experiments.



Photos by R. D. Zweig

Figure 18. *Comfrey before and after feeding to fish.*

Of the 352 fish retrieved from this harvest, 182 were fingerlings and the others were of an edible size. The small fish constituted only 1.1 kg. of the total weight or 3.7% of all the fish. Their numbers were kept low most likely because we removed the fry as we found

[1] W. O. McLarney and J. H. Todd, 1972, "Walton Two: A Compleat Guide to Backyard Fish Farming," *The Journal of The New Alchemists*, 2: 79–111.

[2] L. D. Hills, 1975, *Comfrey Report*, 2d ed.; The Rateavers, Pauma Valley, California 92061.

[3] R. D. Zweig, 1979, "Investigations of Semi-Closed Aquatic Ecosystems," *The Journal of The New Alchemists*, 5: 93–104.

[4] Zweig, 1977, "Three Experiments with Semi-Closed Fish Culture Systems. 3. The Dome Pond," *The Journal of The New Alchemists*, 4: 73–74.

them swimming at the surface of the pool. Fingerling growth may have been inhibited because the commercial feed pellet was much too large for them to eat, although it was eaten rapidly by the larger fish. Small fish are also unable to eat the coarse comfrey leaves. Using this stocking and feeding strategy, it appears that most of the feed will be taken by the larger fish. At the end of the experiment, the larger fish weighed 171 gm. or over a third of a pound on the average. A few were over one pound.

The production from this harvest has proved significant. Although the fish were fed just over four times more than the tilapia in the previous summer's Dome monoculture, the fish grew nearly ten times more. Quite likely this can be attributed largely to the nutritiousness of the comfrey which is hardy and grows rapidly, making it well worth considering as a plant to raise as a fish feed.

The assistance of Deborah Goodwin, Kaaren Janssen and Nancy Wright was invaluable to this project.

Photo by R. D. Zweig

Summary of Fish Culture Techniques in Solar-Algae Ponds

John Wolfe and Ron Zweig

Although the ultimate aim of the National Science Foundation sponsored closed-system aquaculture project is to write "The Compleat Guide to Solar-Algae Pond Fish Culture," we continue, in the meantime, to be inundated with inquiries about how to raise those funny fish in those whatchamacallit fish tanks. We hope, dear readers, that this short summary will at least partially satisfy your craving for information, pending publication of the "Compleat Guide."

Basic Strategy

Algae grow in sunlight and absorb toxic wastes. Fish eat algae, bottom detritus and added feeds. Bottom

sediments (dead algae and fish wastes) are periodically removed.

Dimensions and Materials

Shape: Cylinder on flat base.

Dimensions: Ponds at NAI are 60″ high by 57″ inside diameter. Water volume is 2.4 cubic meters or 630 gallons.

Materials: Sides and base are light-transmitting fiberglass-reinforced polyester (FRP). Units can be purchased from Kalwall[1*] or assembled on site using .04″ Kalwall Premium Sunlite or perhaps Lascolite[2] (tedlar-clad FRP). Seams can be sealed with water resistant epoxies such as Arcon 2795 resin combined with Versamid 140 catalyst[3].

Both outdoor ponds and those in greenhouses need wintertime insulation (vertical reflectors to the north and adjacent ground reflectors help too). An insulating air space can be created with a second layer of FRP around the sides, shimmed out at the top and bottom with rings of discarded garden hose or ½″ flexible plastic pipe. Insulate pond bottom with styrofoam. If pond is indoors, insulate the top with a conical FRP cover. If outdoors, flat lids can be made from sheets of closed-cell styrofoam reinforced with wood, or double-walled inner-ribbed acrylic or polycarbonate sheets (e.g., Tuffak-Twinwall or Acrylite SDP[4]), edges sealed with wide tapes (e.g., duct, or Tuck[5]). Consider wrap-around night insulation for climates with more than 6,000 degree days.

* Superior numbers refer to the list of suppliers following this article.

Algae

Introduce a wide range of wild algae species by adding a few ounces of the greenest pond-water available. Try several eutrophic (overly fertile) ponds. Alternatively, let the pond seed itself. Algae on the fish, along with exposure to spores from the air, are often sufficient to inoculate a pond with algae. Tilapia, grass carp and Israeli carp can keep the pond sides clean of algae.

Feeds

Leafy plants: Confrey plants (35% protein), vetch, purslane and alfalfa, among others. Comfrey (*Symphytum* sp.) can also be ground and dried into pellets for storable feeds.

Zooplankton: Excellent fish food, difficult to culture, they thrive in shaded water rich in organic matter. Zooplankton can also be established in fish ponds by partitioning fish out of an area where the zooplankton can't be eaten to extinction.

Insects: Caught by nets, conical fly traps or Hedlund's bug lights.[10]

Red worms: See Jeff Parkin's "Some Other Friends of the Earth" in the fifth *Journal,* pp. 69–72, for culturing methods. Our bedrun breeders come from Maryland.[11] Feed the worms whole, or blended into ground leaf pellets.

Rabbit feed: Essentially alfalfa and soy meal bound together with corn gluten (20% protein).

Trout feed: First three ingredients are soy meal, fish meal and ground corn (40% protein).

FISH SPECIES AND FEEDING HABITS

	FEED TYPES						
Fish Species	*Planktonic Algae*	*Leafy Plants*	*Detritus*	*Zooplankton*	*Insects & Worms*	*Rabbit Feed*	*Trout Feed*
Blue Tilapia (*Sarotheradon aureus*)[6*]	x	@	x	x	x	x	x
Tilapia hybrid (*S. mossambica* f. x *S. honorum* m.)[7*]	x	@	x	x	x	x	x
Sacramento River Blackfish (*Orthodon microlepidotis*)	x		x	x	x	?	x
Israeli or Mirror Carp (*Cyprinus carpio specularis*)[8]		@	x	x	x	x	x
Grass Carp or White Amur (*Ctenopharyngodon idellus*)[9]		@	x	x	x	x	x
Black, Brown & Yellow Bullheads (*Ictalurus melas, nebulosa & natalis*)			x	x	x		x

*Tilapia die at temperatures below 54°F or 12°C. @ = adult fish

Fish need to be introduced to new water carefully to avoid temperature and chemical shock. Put the fish in a plastic bag, puffed up and tied closed, with little water and mostly air Float the bag in the new water for half an hour (temperature acclimation). Then exchange 25% of the fish's water, three times at ten-minute intervals (chemical acclimation). Release the fish.

Fish Densities

Upper limit is about 20 kilograms or 45 pounds. Optimal density is probably between 3 to 12 kg. or 7 to 26 lb.

Feeding Rates

Maximum (use whichever is lowest): 200 grams dry weight feed per day *or* daily dry weight feed at 5% of live fish weight (can be greater for fingerlings or fry) *or* all the food the fish can eat in three or four hours (use floating feeds to check this). Any feeding rate greater than the number of gm/day listed above tends to deplete oxygen in water.

Optimal: 50–100 gm/day *or* 3% fish weight daily *or* most reliably, the amount of food the fish will eat in 15 minutes.

Minimum: Nothing but inedible organic inputs such as manure. The fish will eat the resulting algae, bacteria and zooplankton. Expect slow growth.

Growth Rates

The food conversion ratio (FCR) is the unit of dry weight feed required to grow one unit of wet weight fish. The FCR for tilapia eating Trout Chow ranges from .8 to 2.0. The tilapia FCR for rabbit feed ranges from 1.5 to 3.0.

The maximum recorded growth rate to date is 106 lb/yr (132 gm/day) over an 82 day trial conducted at Goddard College, using fresh insects for feed. Consistent good growth at NAI is 30–50 lb/yr (45 day 65 gm/day) over 100- trials using dry commercial feeds.

Aeration

In moderately fed ponds, aeration (air bubbling) to supply oxygen is usually needed from two to four hours after sunset to one to two hours after sunrise, except on cloudy days when aeration should begin near sunset. On cloudy days in heavily fed ponds, aeration is needed continuously.

The simplest aeration is to pump air through plastic tubes into air diffusing stones located near or on the pond bottom. An aquarium pump such as the 3 watt Metaframe Hush II[12] can supply two air stones with air. Two to four air stones are needed per pond. On a larger scale (a dozen or more ponds), consider a central air compressor such as the one-third horsepower Condé air pump[13] attached to flexible ¾" plastic piping with smooth curves rather than right-angle bends.

Water Purification

Method #1: Remove bottom sediments and replace with fresh water. If feeding rates are heavy, replace the bottom 20% of the water column every one to three weeks. If feeding rates are light, replace 20% every four to twelve weeks. Irrigate plants with the pond water; it's loaded with nutrients. If you want to become scientific, find an old microscope and look at algae in mid-water samples. Replace bottom water more frequently after seeing major volumetric decreases in algae.

Method #2: Consider a constant fresh water trickle inflow, with an outflow siphoning up from the bottom. Make water replacement equal or exceed the rates described above.

Method #3: Install a sand filter or hydroponics trough just above the surface of pond and slowly flow water through it, preferably drawing from bottom waters. Sand filters out algae and some organics; the plant medium filters out this plus nitrate, ammonia and phosphate. Turn off the flow to the hydroponic filter during the day to allow the plant roots to dry, preventing root rotting problems. Use algae-laden sand from sand filter as plant fertilizer.

Lots of other untested possibilities exist: adjacent settling tanks, conical bottoms with a drain in the center, etc.

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SUPPLIERS' ADDRESSES

1. Solar Components Division
   Kalwall Corporation
   P.O. Box 237
   Manchester, NH 03105
   603-668-8186
2. Lasco Industries
   8015 Dixon Drive
   Florence, KY 41042
3. Allied Resin Corporation
   Weymouth Industrial Park
   East Weymouth, MA 02189
   617-337-6070
4. Tuffak-Twinwall
   Rohm & Haas Company
   Independence Mall West
   Philadelphia, PA 19105
   215-592-3000

   Acrylite SDP
   CYRO Industries
   859 Berdan Avenue
   Wayne, NJ 07470
   201-839-4800
5. Tuck Industries
   1 LeFevre Lane
   New Rochelle, NY 10801
   914-235-1000
6. Texas Water Gardens
   2331 Goodloe
   Houston, TX 77093
   713-694-8801

   and

   Southern Fish Culturists, Inc.
   P.O. Box 251
   Leesburg, FL 32748
   904-787-1360

7. Natural Systems, Inc.
Rt. 1, Box 319
Palmetto, FL 33561
813-772-8911
8. Hiwassee Minnow Farm
P.O. Box 316
Georgetown, TN 37336
615-339-2271
Perry Minnow Farm
Rt. 1, Box 1015
Windsor, VA 23487
804-539-1709
9. J. M. Malone & Son Enterprises
P.O. Box 158
Lonoke, AR 72086
501-676-2800
10. Hedlund's of Medford
P.O. Box 305
Medford, WI 54451
11. Frank Cappadora
Warchime Worm Ranch
3100 Warchime Road
Manchester, MD 21102
301-239-8500
12. Metaframe
41 Slater Drive
Elmwood Park, NJ 07407
201-791-8800
13. Condé Milking Machine Co., Inc.
Pump Division
Sherill, NY 19461
315-363-1500

Photo by Hilde Maingay

Sunlight Patterns Without, Chemistry Patterns Within: The View from a Solar-Algae Pond

John Wolfe David Engstrom Ron Zweig

Sunlight, growth, metabolism, decay; these are the basic elements in the flow of energy through all living systems. The solar-algae ponds, as tiny ecologies, demonstrate the processes well. The patterns of sunlight striking the pond's sides predict the sunlight entering, and the chemistry patterns within trace the balance of plant and animal activity. With imagination, these spatial patterns even predict the future and past of any one point within the ponds. Drawing from the spatial patterns, we can demonstrate the basic process by which sunlight enters the ponds, and by which solar energy is captured by the life within.

Sunlight

Using verified calculation techniques, we can predict how much sunlight gets into a solar-algae pond sitting in a nonreflective, grass-covered field. Unfortunately, no theory exists to tell us how to calculate the amount of sunlight added by nonshiny reflectors such as the white back walls and marble-chip ground cover of the solar courtyard. To understand the reflected radiation from the solar courtyard, we had to measure it directly.

Around noon (when reflection was greatest) on two cloudless days, June 25 and September 29, 1978, we took 72 measurements of solar radiation with an Eppley black-and-white pyranometer, comparing vertical readings on the side walls of the solar ponds in the courtyard with vertical readings taken in a nearby (nonreflective) field. Figures 1 and 2 graphically represent the data collected on September 29.

Figure 1 shows that much of the reflected radiation from the back wall strikes the north face of the ponds. Little radiation bounces up directly from the marble chips to strike the south face. This does not suggest, however, that the marble chip ground cover isn't an effective reflector. The ground and back wall reflectors act together. The chips pass much sunlight to the back wall, which in turn directs this reflected energy into the pond.

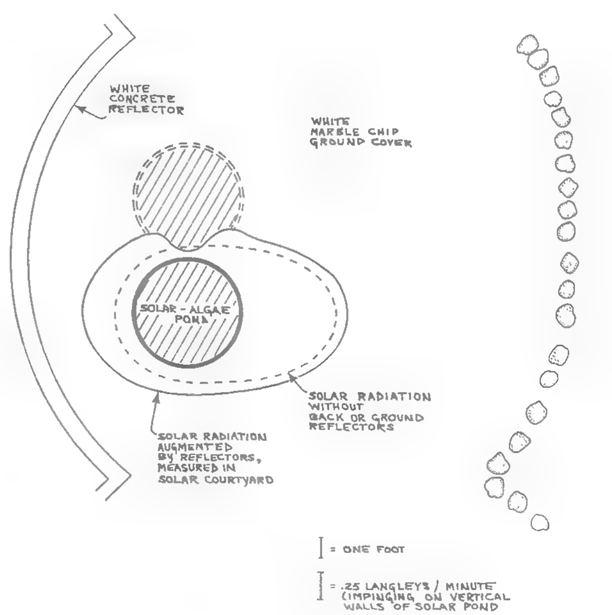


Figure 1. *Graphical representation of the added sunlight.*

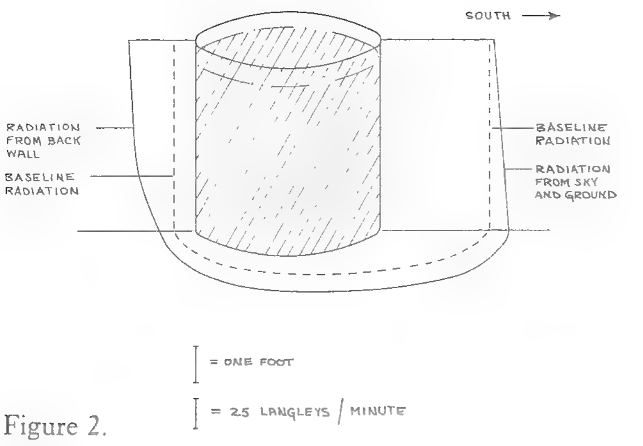


Figure 2.

The side view in Figure 2 shows the reflected radiation does not strike the upper and lower portions of the pond evenly. On the north face, the plant bed running along the base of the back wall absorbs some energy. On the south face, the radiation reflected off the marble chips is more intense near the ground.

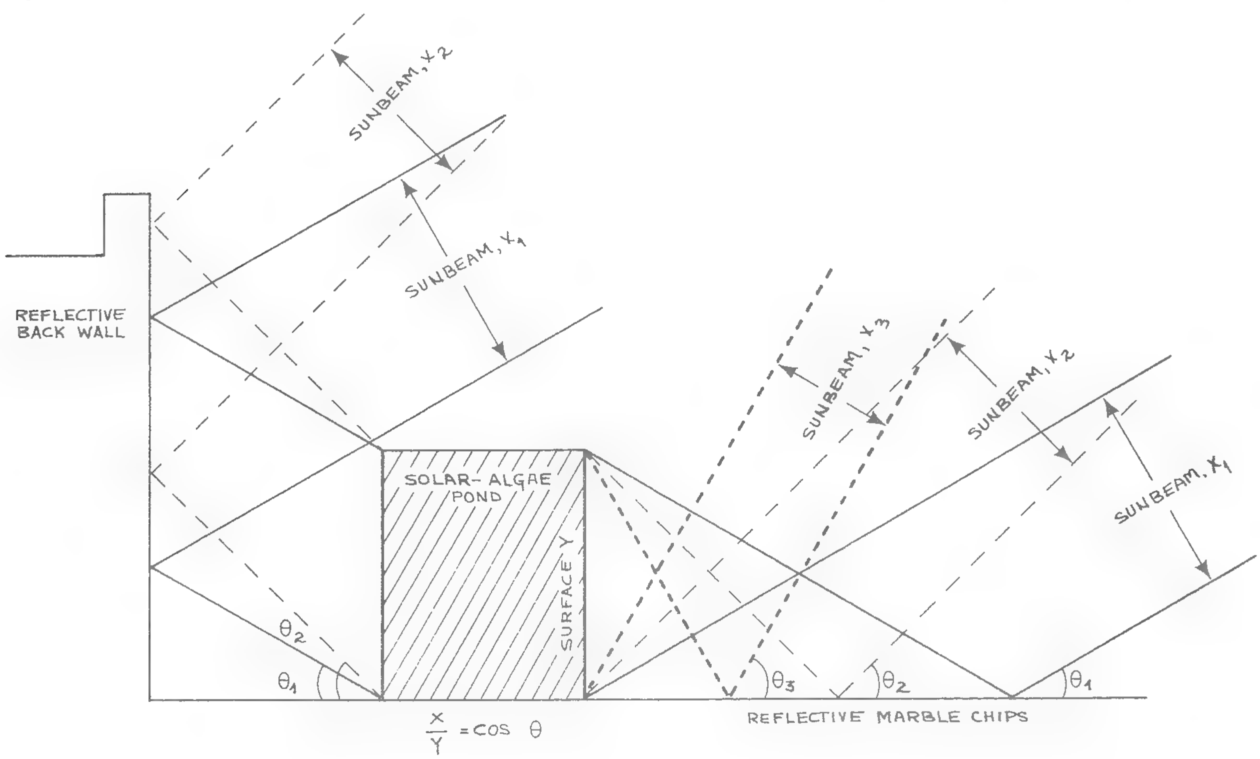
The distribution of sunlight shown in Figures 1 and 2, based on September 29 data, is much the same for June 25. The degree to which reflected radiation adds to the total differs significantly, however. On June 25 reflection added 26% to the radiation entering the pond sides, while on September 29 reflection added 46%. The critical difference between these two dates lies in the altitude of the sun at noon: 72 degrees on June 25, and 46 degrees on September 29.

To understand reflected radiation, we must separate the incoming energy into diffuse and direct radiation. Diffuse radiation, for practical purposes, impinges from all sections of the sky evenly, while direct radiation emanates directly from the sun's position in the sky. In the solar courtyard, reflection from diffuse radiation remains a constant proportion of diffuse radiation, 50% according to measurements. On the other hand, reflection from direct radiation depends on the incoming angle of sunlight. Figure 3 illustrates how reflection from direct radiation is diminished by higher and higher sun angles. In the diagram, the ratio of the sunbeam width seen by the pond, to the height of the pond, determines the diminishment factor. Expressed trigonometrically, this ratio is the cosine of the sun's altitude. Thus, the difference in the degree to which reflection adds to total radiation lies in the incoming angle of direct radiation.

What about times other than noon? We won't go into details, but only say that reflection is diminished by roughly the cosine of the sun's azimuth angle--that is, the angle between due south and the sun's horizontal, or compass, position. The further from solar noon and due south, the less reflection, until at 90 degrees (due west or east), no reflection of direct radiation from the back wall occurs (the cosine of 90 degrees is zero).

This deeper understanding of reflected radiation led us to develop a computer simulation program to predict the yearly amount of sunlight entering the solar courtyard ponds. We won't bore the reader with long trigo-

Figure 3.



nometric formulas and algebraic functions, but rather give a running account of how the program works. (For the details, see *Solar Energy Thermal Processes*, by John Duffie and Wm. Beckman, 1974, published by John Wiley & Sons.) First, solar radiation data collected by Dr. Richard Payne for the nearby Woods Hole Oceanographic Institution (10 miles south of us) is converted from daily totals for radiation striking a horizontal surface to the most probable hourly totals for the direct and diffuse radiation components. For each 10 minute period the computer converts the direct radiation to its full strength when striking a plane at right angles to its path, and the sun's position from which the radiation comes is calculated. Then the program calculates the angle between the direct sunbeam and each plane of a many-sided polygon closely approximating the shape of the cylindrical solar ponds. The intensity of sunbeam is diminished by a factor representing how obliquely the radiation hits each of the pond sides; this factor is simply the cosine of the incident angle (see Figure 4). The radiation is diminished further by the fraction of radiation actually penetrating through the pond sides, rather than being reflected off or absorbed by the two layers of Kalwall Sunlite Premium II fiberglass glazing (see Figure 5). This factor is also determined by the angle of incidence. Diffuse radiation is easier to calculate since it has a constant 43% radiation diminishment factor for two layers of Kalwall.

Applying our knowledge of reflected direct radiation, the program compares the cosine of the sun's altitude and azimuth each hour to that at noon on September 29; the 46% addition of reflected radiation to direct radiation at noon on September 29 is adjusted upwards or downwards accordingly. Reflection enhances diffuse radiation by a constant 50%.

Two other factors change from month to month rather than from hour to hour. One is a shading factor

Figure 4.

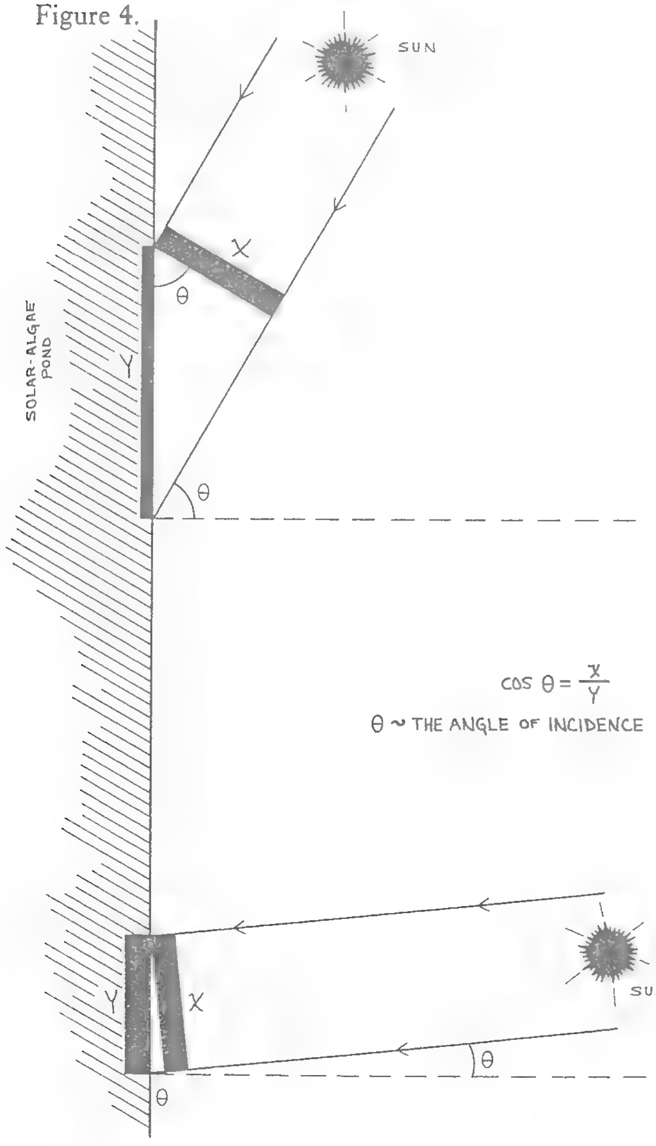


Figure 5.

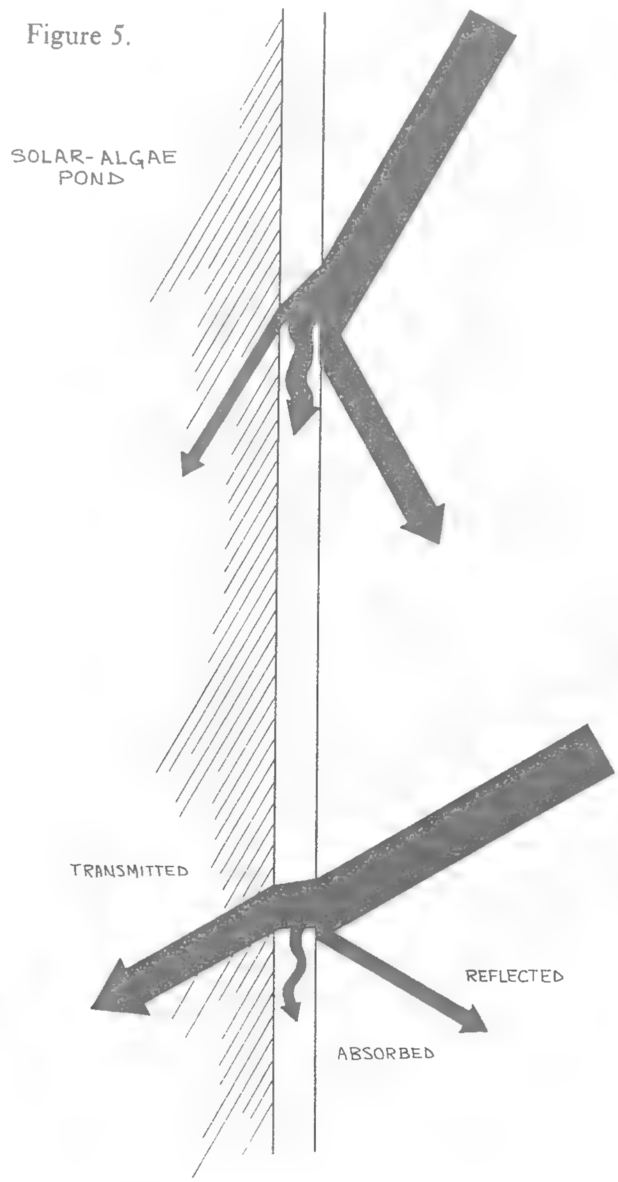


TABLE 1—Output of Computer Simulation of Energy Entering a Solar-Algae Pond in the Solar Courtyard.

Month	Average Daily Horizontal Radiation (cal/cm² day)	Presence of Winter Lid	SOLAR ENERGY ENTERING POND (million calories per day) Horizontal	Reflected	Vertical	Total
Jan	170	x	2.03	3.36	6.36	11.80
Feb	210	x	2.45	3.16	6.24	11.90
Mar	302	x	3.32	3.26	6.77	13.30
Apr	443	x	4.71	3.48	7.57	15.80
May	508	x	5.39	3.46	7.55	16.40
Jun	477		8.90	3.25	6.98	19.10
Jul	564		10.20	3.53	7.77	21.50
Aug	462		8.68	3.31	7.25	19.20
Sep	322		6.67	3.02	6.40	16.10
Oct	223	x	2.55	2.86	5.79	11.20
Nov	143	x	1.89	2.53	4.92	9.34
Dec	117	x	1.69	2.50	4.77	8.97
Yearly Total (*billion calories*)			1.78	1.15	2.38	5.31

from the plants growing at the base of the back wall reflector. The second is whether or not the winter lids of the ponds are on. Without the lids, the only thing reducing incoming radiation is reflection off the water surface. With the lids, light transmittance is treated in the same way as light penetration of the sides of the ponds.

Table 1 lists the estimates of the amount of radiation entering the solar courtyard ponds each month, based on Payne's solar data for 1977. Because of low winter sun angles and the pond lids, far more radiation penetrates the sides of the ponds in the winter, while in the summer, the discrepancy between sunlight entering the sides and top lessens.

CHEMISTRY

The solar-algae ponds receive three major energy inputs: (1) sunlight, (2) fish feeds, and (3) bubbled air. These three energy inputs induce the spatial patterns of water chemistry found within the ponds. The air bubbling, or "aeration," provides oxygen at night, augmenting the photosynthetic oxygen produced by solar energy. The feeds supplement the energy that is available to the fish from eating algae. It is interesting to note that the algae capture at most only a small percentage of the sun's energy for growth; the rest becomes heat soon after striking water and algal cells. Since only a fraction of the solar energy embodied in algal growth can be assimilated by the tilapia, it appears that fish growth based soley on phytoplankton growth with the ponds could achieve at most 20 pounds of fish growth annually (J. Todd, R. Zweig, et al., "Assessment of a Semi-Closed, Renewable Resource Based Aquaculture System," May 1978, pp. 70–71).

Figure 6 illustrates the variations of temperature, oxygen and pH found during one bright June afternoon in two heavily fed solar-algae ponds. In these drawings, each line or "isocline" within the pond represents a single temperature, oxygen or pH value much like a line on a contour map represents points of equal elevation.

The temperature profile reveals the basic water circulation pattern within the two ponds. The patterns are quite different since the aeration system of one pond mixes the water continuously while that of the other shuts off soon after sunrise and turns back on only after sunset. Both ponds are coolest at the bottom since cool water tends to sink below warmer water. The nonaerated pond has a greater temperature difference from top to bottom (2.5°C. vs. 1.5°C.), as indicated by the greater mumber of isothermal lines. The one area where the nonaerated pond seems well-mixed is near the top, where it seems to be churned by the wind.

The nonaerated pond exhibits a warm-water outer shell and an inner core. Cooler water rings the warm core. The pattern suggests a thermo-siphoning loop: water warmed at the outer sides convects upward, creating a complementary downward suction at the pond's center (see Figure 7). Since Figure 6 is a cross-sectional view of a cylinder, the side upwelling and central downcurrent is quite evident, while the return loop across the bottom of the pond isn't apparent since that loop radiates in all directions across the bottom, making the flow to the exact north and south quite small. The aeration system forces the circulation loop in the second pond. Figure 7 shows the long loops generated by two pipes holding air bubblers within that entrain water upwards with the rising bubbles.

These circulation loops buffet and shift a basic oxygen and pH pattern arising from the balance of photosynthesis and respiration within the pond. Quite

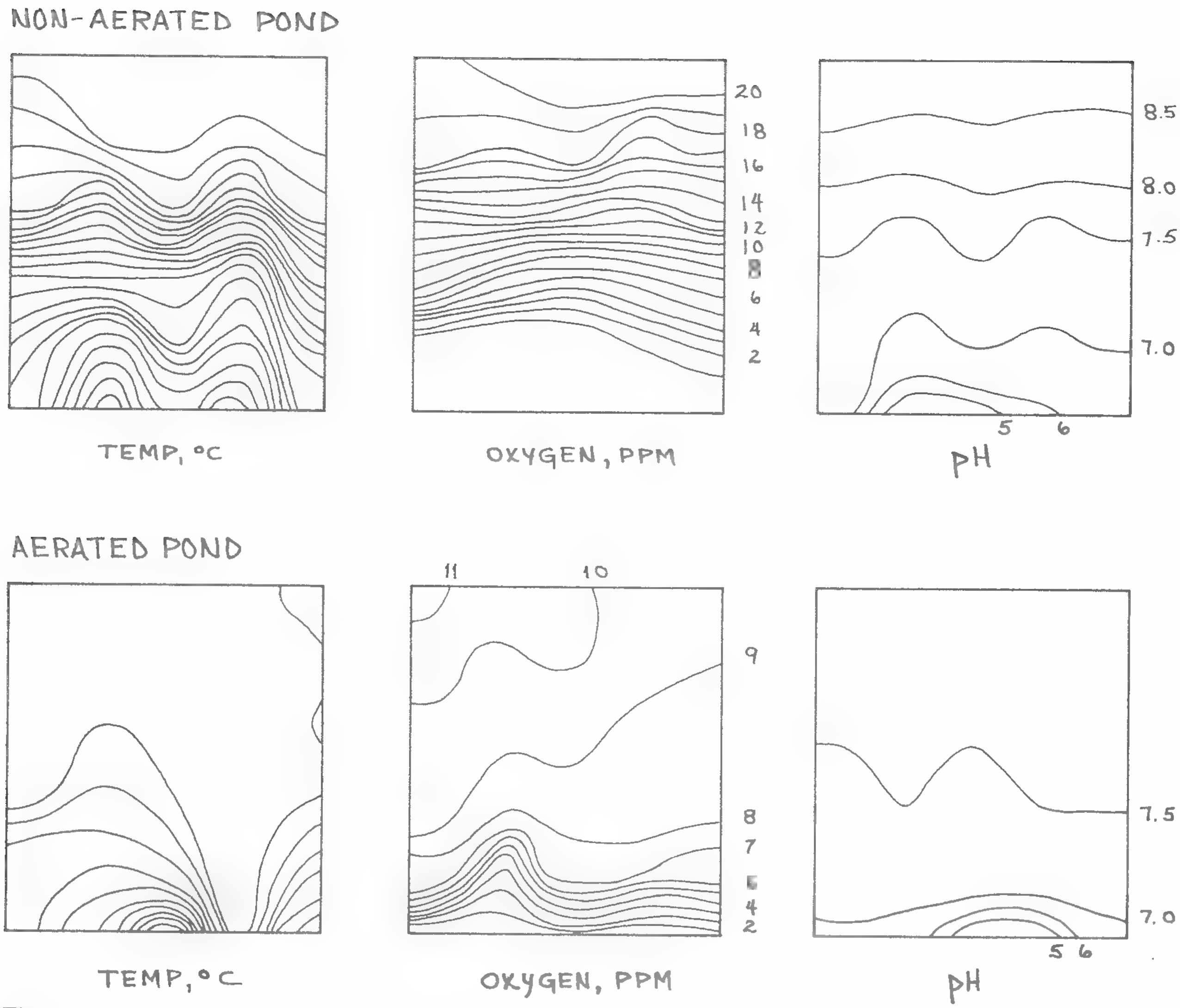


Figure 6.

simply, sunlight-bathed, photosynthesizing algae produce oxygen and absorb carbon dioxide, where as algae respiring in the dark along with fish, bacteria and zooplankton, consume oxygen and release carbon dioxide. Since a portion of the carbon dioxide becomes carbonic acid, respiration increases acidity and lowers pH while photosynthesis reduces acidity and raises pH. Photosynthesis and respiration also involve the assimilation and release of elements such as nitrogen and phosphorus, but our concern here lies with carbon and oxygen.

Biological processes create a basic pattern of water chemistry that water currents can shift but can't mask. During the afternoon of our measurements, the basic pattern was (1) intense oxygen production near the top and sides of the pond, (2) moderate net oxygen consumption by respiring plants and animals in the dark core, and (3) intense oxygen depletion near the bottom sediments of dead algal cells and fish wastes (look back at Figure 6). The pH follows a similar trend, since high pH indicates low carbon dioxide concentrations. Surprisingly, the patterns of all three variables (O_2, pH, temperature) are similiar, with high values in upper waters, lower values in deeper areas, and the distribution of well-mixed and still, stratified patches determined by the water currents.

Figure 8 presents average oxygen concentrations for each depth in the two ponds on the same afternoon.

Figure 7. *Circulation loops within the ponds.*

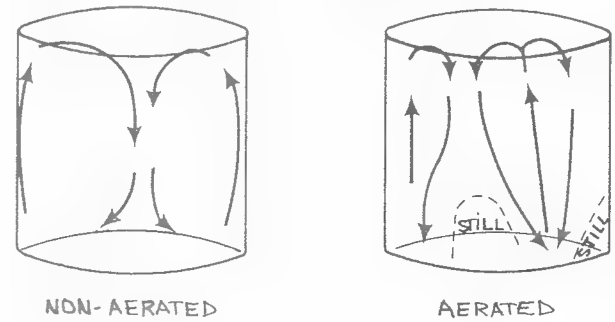
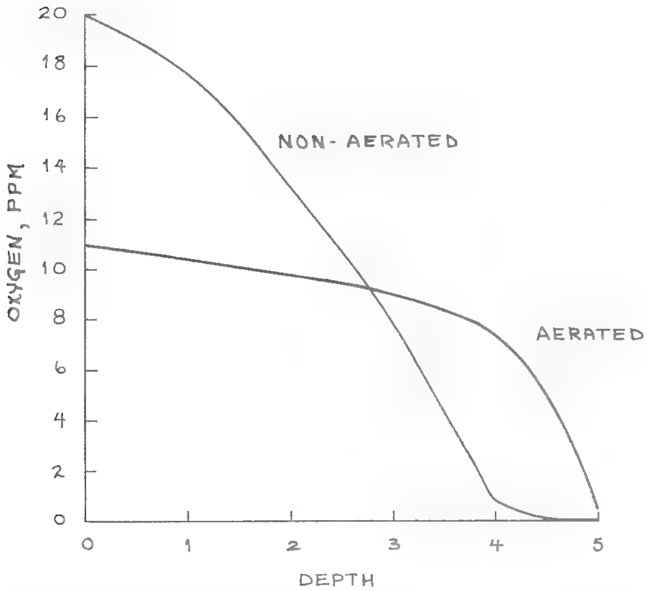


Figure 8. *Oxygen in aerated and non-aerated ponds.*



The anoxic or oxygen-poor zone extends upwards much further in the nonaerated pond (refer also to Figure 6), but oxygen levels also rise much higher in the upper water. These high oxygen values, far above the 7.8 parts per million (ppm) expected if the pond water were in equilibrium with the air, could not occur with aeration. At oxygen concentrations above saturation (7.8 ppm), aeration actually drives oxygen out of the water, since it increases the water-air exchange rates. The aerated pond has an oxygen concentration nearer saturation and lower than the nonaerated pond (7.9 vs. 9.9 ppm). Total oxygen consumption in the aerated pond may also be greater than in the nonaerated pond if the water movement brings sediment particles up into the water column to decompose rapidly in the relatively oxygen-rich upper waters, rather than leaving the organics sequestered in the anoxic, slowly decomposing bottom sediments.

The ponds exhibit a pattern of evolution through time that parallels the vertical spatial pattern. In newly filled and inoculated ponds, the low algae densities allow each algal cell to receive nearly the maximum possible amount of light. The young, vigorous algae produce tremendous amounts of oxygen, and absorb all available carbon (dissolved carbon dioxide, and at high pH, even bicarbonate ions) for growth, pushing pH very high. After a time the algae increase to self-shading densities, where respiration over the day/night cycle nearly equals daytime photosynthesis. This is the maximum sustainable density of algae; algae will die at the same rate as new cells are created. Often, the inertia of population growth pushes the algae beyond the maximum sustainable density, and the algae populations "crash." In any case, gravity pulls the algae and solid fish wastes to the bottom, where bacteria decompose the detritus, lowering pH and oxygen levels in the process. Microscopic animals that feed on the bacteria (e.g., ciliated protozoans) flourish as a result.

Meanwhile, supplementary fish feeds are constantly added. The feeds add to oxygen demand directly by increasing fish biomass and metabolism. More importantly, the wastes from feeding increase the density and activity of bacteria and zooplankton. With it, oxygen demand and carbon dioxide production grow. Eventually, anoxic and acidic conditions will develop on the pond bottom. If unchecked, the low oxygen and pH condition will slowly spread upwards. At this point, the balance between photosynthesis (growth) and respiration (decay) can shift so far toward respiration that fish culture may become impossible.

The spatial patterns of the ponds in Figure 6 reflect their transformations through time. The top of the ponds are supersaturated in oxygen and high in pH, reminiscent of conditions prevalent throughout a young, freshly inoculated pond. The center of the ponds have lower levels of oxygen and pH, indicating more respiration relative to photosynthesis, and revealing a mature pond, rich in both plant and animal activity. The bottoms of the ponds are nearly anoxic, much as a pond over-enriched with organics would appear throughout. The two ponds shown in Figures 6–8 are approaching the end of their transition from growth to decay since pH and oxygen drop to low levels every night.

Low oxygen and pH can probably be avoided indefinitely with simple low-head, low-flow sand or hydroponic filters. Alternatively, siphoning the organic slurry from the pond bottom and replacing it with fresh water can actually freshen and rejuvenate the ecosystem, starting the cycle anew.

We are indebted to Deborah Goodwin, Kaaren Janssen and Ken Winniac for help in collecting the data used in this paper.

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Photo by R. D. Zweig

The Energetics of Solar-Algae Pond Aquaculture

John Wolfe

In assessing the potential of a technology for a solar society an essential question is, how much energy is required to build and operate the technology relative to the energy, food and other benefits it provides. At New Alchemy we have directed that question to the biologically rich, heat-storing, solar-algae ponds. This paper quantifies the energy required to manufacture and operate solar ponds, and compares these inputs to the solar heat and fish protein produced.

An input/output matrix of energy-flows through the U.S. economy, developed by the Center for Advanced Computation (C.A.C.) at the University of Illinois, allows us to assign energy values to solar pond construction and maintenance.[1] The researchers at C.A.C. based their matrix on the concept of embodied energy flow; this flow occurs whenever there is a movement of energy, goods or services from one economic sector to another. The flow is expressed in terms of the total primary energy needed to produce the economic entities that are being transferred. For example, the energy associated with the movement of coal to the paper industry represented 364 trillion Btu. in 1967. That figure slightly exceeds the energy value of the coal received by the paper mills because it takes some energy to build and run the equipment to mine and transport the coal. A computer algebraically manipulates the matrix that represents such embodied energy flows to yield the energy used by each economic sector. The energy embodied in a dollar's worth of the product of each sector can then be calculated.

Applying embodied energy values to our case, each pond requires approximately $25 in aeration equipment. Deflating to $12.50 in 1967 dollars and multiplying by 86.4 thousand Btu./1967 dollars (the energy intensity of the Fabricated Metal Products sector) yields an energy cost of roughly one million Btu. to produce the aeration equipment. Since the equipment lasts ten years, the annual energy cost, not including the energy consumed during the operation of the equipment is one-tenth of the total.

The ponds do produce—or more accurately, save—energy. During the day the ponds absorb sunlight directly, converting it to heat which warms the volume of water. They also soak up heat from the air when daytime air temperatures climb higher than those of the water. This tends to prevent the Ark from overheating. At night, when air temperatures fall below those of the pond, heat is drawn back out of the water. The ponds can store enormous amounts of heat; 2,400,000 calories are released when a pond cools just one degree Celsius.

We can then calculate (roughly) and list the energy inputs and outputs to and from a pond, as shown in Table 1. Two values have been omitted for simplicity's sake: the output of plant fertilizer and the input of energy to construct the surrounding bioshelter. Since

TABLE 1 Annual Energy Inputs and Outputs of a Solar-Algae Pond. (Units Are in Million Gram Calories Unless Specified Otherwise.)

Location	*Ark*		*Solar Courtyard*	
Amount fed	*60 lb.*	*120 lb.*	*60 lb.*	*120 lb.*
Inputs				
Fiberglass Tank	182	182	243	243
Reflective Chips	0	0	50	50
Reflective Wall	0	0	286	286
Aeration Equipment	28	28	28	28
Aeration Electricity	238	238	238	238
Feeds	73	146	73	146
Labor	2	2	2	2
Total Inputs	523	596	920	992
Deducting Multi-purpose Tanks	−182	−182		
Aquaculture-Specific Inputs	341	414		
Outputs				
Heat Savings in Ark	900	900		
Dry Weight Edible Protein (Total Growth = 50 & 100 lb)	2.45 kg.	4.90 kg.	2.45 kg.	4.90 kg.

[1] Clark Bullard III, Bruce Hannon, and Robert Herendon, Center for Advanced Computation, 1975. Energy flow through the United States economy (wall chart. University of Illinois at Urbana-Champaign Press).

the building performs many other functions, the latter omission is reasonable. Two fish production figures, with different associated feeding rates, are used. The first figure, 50 pounds per year, reflects a growth rate that has been attained consistently over the last few years in many of the experiments at New Alchemy. I base the second growth rate, that of 100 pounds per year, on growth spurts of short duration (two weeks) that we have seen, and on a long-term growth rate of 106 pounds per year achieved by Barry Pierce at Goddard College during the summer of 1978. Barry's secret was to feed insects to his fish, a strategy we closed-system aquaculturists at New Alchemy have strayed from. Barry's demonstration, reinforced by grumblings from Bill McLarney and Susan Ervin, are bringing us back around.

The energetic analysis in Table 1 proves extremely useful because it identified areas where energy inputs might be drastically lowered. Inside the Ark, aeration electricity demands the largest portion of the energy budget. A small, 6 to 7 cubic foot per minute, ⅓ h.p. air compressor now supplies air to all the ponds in and adjacent to the Ark. The power requirement of the compressor averages to 25 watts for each pond. Some low-wattage aquarium pumps, such as the Metaframe Hush II, can drive air to the bottom of the ponds. One for each pond might prove adequate. The two-air-line, three-watt Metaframe pump could reduce aeration energy requirements eight-fold. In the solar courtyard, the concrete back reflector adds a large energy cost but does add 45% more light to the outside ponds (see the discussion of sunlight in the solar courtyard on pages 100–105), probably preventing them from freezing in winter. Yet other less energy costly possibilities exist. The ponds could be triple-glazed with a middle layer consisting of high-light transmittant solar film and be given an airtight clamp lock for the top flap. Or a flexible insulation layer could be wrapped around the pond, doubling as a daytime reflector.

In comparing inputs to outputs we can take three approaches. The first subtracts total system energy costs from energy benefits, and compares that total to fish protein production. The second compares pond capital costs to heat output, and then pits the additional aquaculture energy inputs against protein output. The third examines the ponds outdoors in the solar courtyard, where insulating lids and adjacent reflectors increase the energetic costs and no heat storage benefiting a larger building occurs. Table 2 summarizes the energy-cost-per-gram-protein figures generated in the three analyses.

The first approach deserves further comment. Positive kcal/gm protein numbers show that unlike most other protein producing systems, solar-algae ponds have an energy benefit rather than an energy cost associated with them. (I do not wish to push this approach too far, lest the scientists growing a few catfish in the heated effluents of power plants argue they get a megawatt-hour of electricity with each gram of protein they produce.) The second approach seems preferable.

TABLE 2—Kcal Spent or Saved per Gram Edible Fish Protein Produced in New Alchemy Solar-Algae Ponds.

	GROWTH	
	50 lbs/yr (Attained)	*100 lbs/yr (Achievable*
Total Energetics in Ark	$\frac{900-523}{2.45} = +77$	$\frac{900-596}{4.9} = +62$
Aquaculture-Specific Energetics in Ark	$\frac{-341}{2.45} = -140$	$\frac{-414}{4.9} = -84$
Aquaculture Energetics in Solar Courtyard	$\frac{-920}{2.45} = -375$	$\frac{-993}{4.9} = -202$

Table 3 summarizes this analysis by placing solar-algae pond fish culture in the context of a wide spectrum of protein-producing methods. Notice that the range of indoor solar-algae pond culture (calculated by the second approach) brackets Israeli pond polyculture, commercial egg production and tuna fishing. Grains cost less, meats and luxury seafoods much more. The energy costs listed here do not include

TABLE 3 –Kcal of Energy Used to Produce Gram of Edible Protein. (Edible = Eventually Eaten Portion, Not Yet Stored or Cooked.)*

+ 77	Tilapia in Cape Cod Ark, w/Heat Credit, 50 lbs/yr
+ 62	Tilapia in Cape Cod Ark, w/Heat Credit, 100 lbs/yr
– 12	Maine Herring
– 14	Wheat
– 28	Atlantic Ocean Perch
– 40	Rice
– 50	Pacific Salmon
– 84	Tilapia in Cape Cod Ark, 100 lbs/ yr
– 110	Israeli Pond Polyculture
– 132	Eggs
– 135	Tuna
– 140	Tilapia in Cape Cod Ark, 50 lbs/yr
– 143	Cod, Haddock, Halibut
– 202	NAI Seasonal Polyculture in Solar Courtyard, 100 lbs/yr
– 238	Hawaiian Prawn Cluture
– 250	Chicken
– 263	Milk
– 310	Pork
– 375	NAI Seasonal Polyculture in Solar Courtyard, 50 lbs/yr
– 650	Hawaiian Oyster Culture
–1,140	Range-Fed Beef
–1,330	Feed-Lot Beef and Gulf Shrimp
–1,700	Maine Lobster

* References for Table 3 (figures from references adjusted to reflect protein yields after processing):

Bardach, J. E. 1978. "Energetics of Aquaculture." Unpublished. Manuscript sent to J. H. Todd 8 10 78.

Pimentel, D.; Dritshilo, W.; Krummel, J.; and Kutzman, J. 1970. *Science*, 190: 754.

Rawitscher, M., and Mayer, Jean. 1977 *Science*. 198: 261

storing or cooking costs. Nor are the protein outputs corrected for protein quality by NPU (net utilizable protein) factors. Thus grains, with their long cooking times and low protein quality, may ultimately cost as much energetically as eggs and Ark-grown tilapia. Similarly, tuna from a can costs more energetically than tilapia caught from the Ark and eaten fresh, although energy costs at the time of harvest are equal.

With the perspective that Table 3 gives, and noting that if anything, its bias is against solar-pond aquaculture, we see that solar-algae ponds offer a unique solution to the problem of creating valuable protein in an increasingly energy-scarce world.

This project has been supported in part by the National Science Foundation Grant #OPA 77-16790A01.

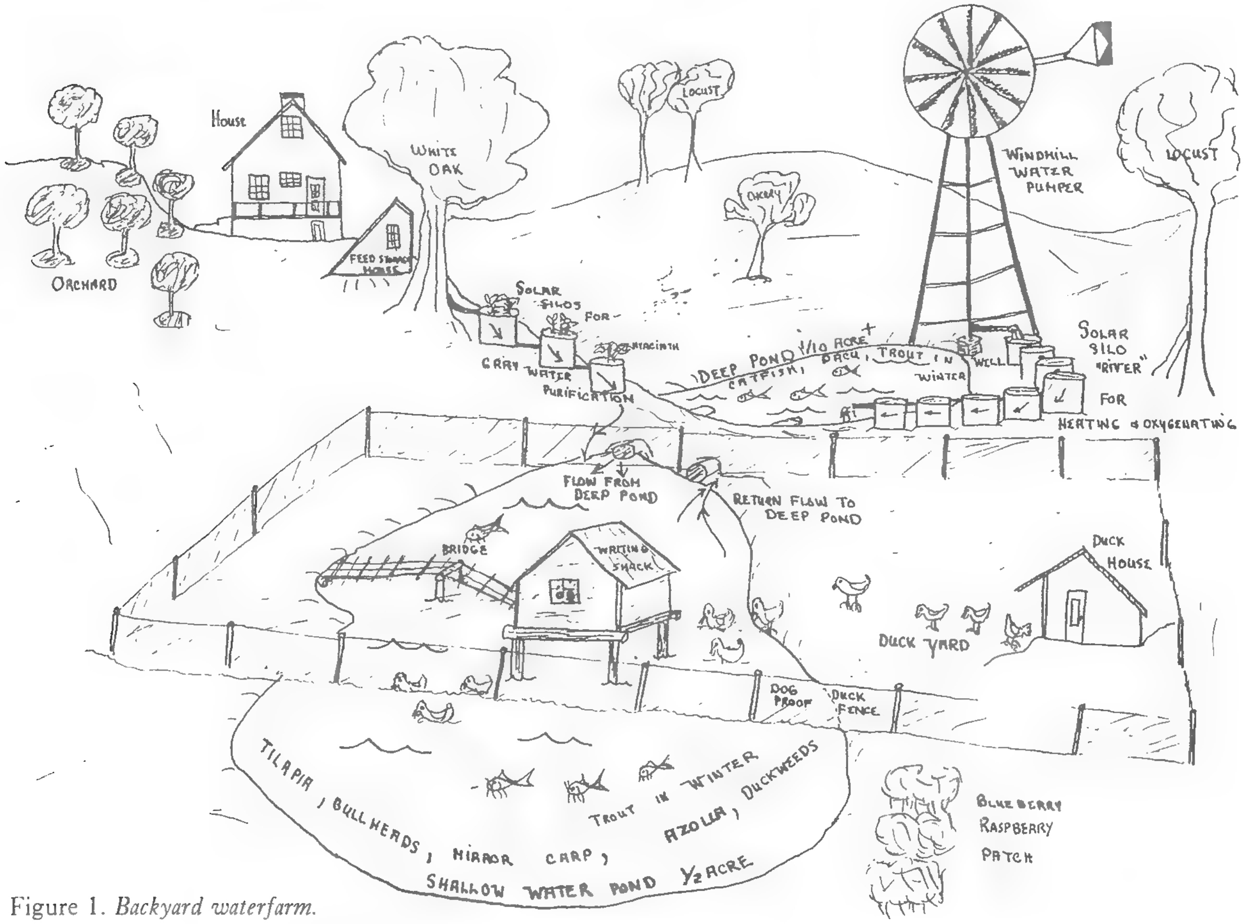


Figure 1. *Backyard waterfarm.*

Dreaming in My Own Backyard

John Todd

I had just finished my income tax forms one April afternoon and realized with shaking hands that I owed money to the Internal Revenue Service, incontestable proof that it has become increasingly hard to ignore that living costs were going up faster than my income.

Gloomily, I retreated to the pond in my backyard to find my bearings and to forget the tax man. It was, thank God, the first warm day of spring and, as I settled down, I discovered the muscovy and mallard ducks and my zany goats seemed happy to share this spot with me. I did, mind you, bring along a little extra corn to bribe my way into their company. We were soon joined by my then nine-year-old daughter who sensed my worries.

As the sun and my friends helped me to forget, the place began to come alive with the sounds and the smells of spring. I live in a small, vest-pocket valley that is treed mainly with oak, locust and cherry. By local standards, some of the trees are very large. Seven years ago on the north-facing slope, next to the road, I

planted a small orchard of twenty varieties of apples, peaches and plums. The house, a typical small Cape Codder, sits on a terrace just below the orchard.

Behind the house, the land drops off, steeply in places, into a basin then ascends again to my neighbor's house. The south-facing slope is a real sun catcher. The bottom of the basin is covered by a half-acre pond that extends into the yard of another neighbor to the east. In the middle of the pond is a shack on stilts which I built as a writing house that is reached by crossing a rickety bridge. I like working in the shack surrounded by water. It feels right. I am not sure why, but it helps to center me.

I am lucky to live in the woods, close enough to the sea to hear the foghorn and the storm-tossed surf. Yet I am still nagged by the bills and the tax man. To further complicate matters, I plan to build a solar addition to the house that will include a greenhouse and tropical fish tanks which will serve double duty as solar heat storage units. It's an exciting project, dimmed only by the prospect of more than doubling my mortgage.

On the grassy patch next to the pond, I enjoyed the warmth and the stillness broken only by bird song. Although I couldn't feel it, the wind blew stiffly overhead and the gulls rode its wave at tree-top height. My daughter and I got up to follow the goats over to an old abandoned stone well. As I stared into the well, an idea began to form. For a moment I saw the land anew—the ponds, the slopes, the house above, and the ducks. I recollected that several years ago my son, in a single season, had grown bullheads to eating size in the shallow, fertile pond. My mind was drawn back to the well. The water level this spring was a foot from the top. The well was a key.

My head swam with two streams of thought, the worry over money on the one hand and, on the other, the formulating dream of wedding sun, wind, the well, ponds, aquatic plants, fishes and ducks to create a mini-farm in this backyard. What if I were to think this through carefully? My water farm might ease my financial burden by helping to pay for the new mortgage and for some of the household running costs. Might this be a sound way towards greater financial independence?

I began pacing the property, banging on my pocket calculator, designing the backyard water farm and becoming more excited as the sketches and plans started to unfold (Figure 1).

It became clear that the existing pond was too small to do the job as it stood. It wouldn't produce more than a few hundred pounds of fish a year. However, at its western end is an old, elevated wagon road, and beyond it, between the road and the well, there is room for a second, deeper, 1/10 acre pond. But to be really productive there would have to be some flowing water too. The wind funnels down our valley, so I imagined an American multiblade windmill pumping well water into the ponds when the wind is blowing. Such a windmill would increase the productivity of the water farm by an order of magnitude, or so I hoped. I have yet to work out all the design details but it would seem wise to pump the well water up into a series of solar-algae ponds (yet to be described) and then down into the new pond. The course of the water would go from the well, through a series of solar tanks into the first pond, then via duct into the second, existing pond. The water would be recycled as it overflowed from the second pond back into the first. The exchange between the two would be dynamic, depending on the wind and the respective water levels. I had created in my mind a symbiotic, wind-powered water loop between the new 1/10 acre pond and the shallow, ½ acre existing pond.

I then planned to pump the water into a series of interconnected, translucent, fiberglass tanks five feet high by five feet in diameter. Five or six of them would be adequate to absorb solar heat and to oxygenate the well water by photosynthesis before it entered the new pond. Running the water through a zigzag course of black pipe would be a cheaper way of heating it but would neither oxygenate it nor provide auxiliary feeds and would lack any storage capacity which might be needed during conditions of low oxygen. With such a scheme I might take a close look at the cost benefit value of a solar "river" composed of a series of solar-algae ponds as a way of optimizing the over-all system.

My plan would include an emergency ¼ to ½ h.p. electric or fuel-fired pump for periods when it is hot and windless, and oxygen would drop to dangerous levels. It would be there for insurance, and I would hope that I wouldn't have to use it. Electric aerators are not a good answer and encouraging their use would serve to buttress the arguments of utility people who are promoting nuclear power plants.

The ponds would be designed as diverse ecosystems to provide a good amount of the dietary needs of the fish. Nutrients would enter the ponds from several sources. Our household gray-water would be piped through three solar-algae ponds containing water hyacinth, aquatic ferns, duckweeds and algae. This way we wouldn't pollute the ground water, as we now do. The water-purifying aquatic plants, in turn, would be fed to the ducks and fish.

The ducks would be another major nutrient source. At the present I have only half a dozen, but in my mortgage-paying ecosystem, I would plan on 250 or so in a 680 square yard fenced impoundment that would be connected to the half-acre pond. Their manure would fertilize the pond. The remaining major nutrient input would be supplemental feeds for the fish and the ducks. Up to 12,500 pounds might be added to the system each year. A substantial percentage of it would enter the various food chains within the pond.

Fish culture would be seasonal and vary between the larger, shallow pond and the deep, new pond. The warm-season crop in the shallow pond would include yellow bullheads, *Ictalurus natalis*, which are relatively fast-growing omnivores, blue tilapia, *Sarotherodon aureus*, a plankton and plant feeder and quite possibly mirror carp, *Cyprinius carpio* var. *specularus*, a benthic or bottom feeder. All three like warmish water and can withstand short periods of low oxygen. Ten thousand fish grown over a six month period starting in April might well, with fairly heavy supplemental feeding and frequent water exchange, reach a marketable weight of 3,000–5,000 pounds. It is a guess, but I don't think an unrealistic one.

Between October and April another 500 to 1,000 pounds of fish like rainbow trout might be grown with the addition of sun-warmed well water, although this figure is pure speculation. I have never raised trout this way before.

The small pond would be deeper, perhaps five feet in all. Though it would be connected to the shallow pond, it might be less enriched with nutrients because it would receive the well water first. It would be here that I would cultivate channel catfish, *Ictalurus punctatus*, and if I could get them cheaply enough, white catfish, *Ictalurus catus*. I would also like to try the fast-growing exotic characin, *Collosoma* sp., a fish that eats, and tastes like, fruit. If the small pond remained warm for long enough, I might get 1,000–2,000 pounds or more of marketable flesh from this pond. In the winter, trout should do well and perhaps add another 500 pounds to the total.

Marketing would be retail. Most of the customers would come looking for the crop. Some of the harvested fish would be kept in solar-algae ponds for live sale, to local restaurants perhaps among others. Some of the fish might be sold fresh once a week through the local health-food store. The remainder I could cold smoke in a new smokehouse built recently at New Alchemy using personal funds. Smoked tilapia and bullheads are mouth-watering, and sell for prices that fatten the pocket book.

As part of the whole design process, I diagrammed the energy, material and money flows through the water form (Figure 2). On the back of the nearest envelope (the one containing my electricity bill), I tabulated some of the economics (Table 1).

A first pass suggested that there definitely was something to my backyard plan and that I should consider making it a reality. With some care and attention I might obtain between 5,000 and 8,500 pounds of marketable fish a year. As the crop is small and the local market hungry for both smoked and live fish, it should be possible to gross between $8,500 and $15,000. The smoked fish sell at a minimum of $2.00 a pound. The remainder, I think, I could retail at an average of $1.50 per pound. Tilapia, which are low on the food chain, when sold as St. Peter's fish, should command even higher prices with organic food buffs. With a little advance notice before harvesting, I ought

TABLE 1—Back-of-the-Envelope Calculations for a Backyard Water Farm

Costs	*Amounts*
Initial Fixed Costs:	
1. Backhoe	$ 500–$ 500
2. Chicken Fencing	$ 600–$ 600
3. Windmill plus Tower	$2,000–$3,000
4. Solar Silos	$ 800–$1,600
5. Emergency Pump—Used	$ 50–$ 100
6. Duck House (Scrounged Materials)	$ 0–$ 0
	$3,950–$5,800
Annual Costs:	
1. Labor	$ 0–$ 0
2. Fuel or Electricity for Pump	$ 25–$ 50
3. Feeds	
A: 5,000–8,000 lbs. catfish trout feed	$1,250–$2,000
B: 2,500–3,000 lbs. rabbit feed for tilapia/carp	$ 250–$ 300
C: 1,000–1,500 lbs. of marine fish waste	$ 100–$ 150
4. Young Fish and Ducks (Bullheads Locally Trapped and Tilapia Locally Produced	$ 500–$1,000
	$2,125–$3,500
Fixed Costs Amortized Over Six Years	$ 658–$ 967
TOTAL ANNUAL COST	$2,783–$4,467

Production and Income		
Marketable Output:		
Pond 1 – 3,000–5,000 lbs (three species) 500–1,000 lbs. trout		
Pond 2 1,000–2,000 lbs. catfish 500 lbs. trout		
Total ...5,000–8,500 lbs., plus 250 ducks for Thanksgiving market		
Income:		
2,000–4,500 lbs. cold-smoked	$2.00 lb.	$4,000–$ 9,000
3,000–4,000 lbs. live fresh	$1.50 lb.	$4,500–$ 6,000
250 Ducks	$3.00 apiece	$ 750–$ 750
		$9,250–$15,750
NET RETURN PER YEAR		$4,783–$12,967

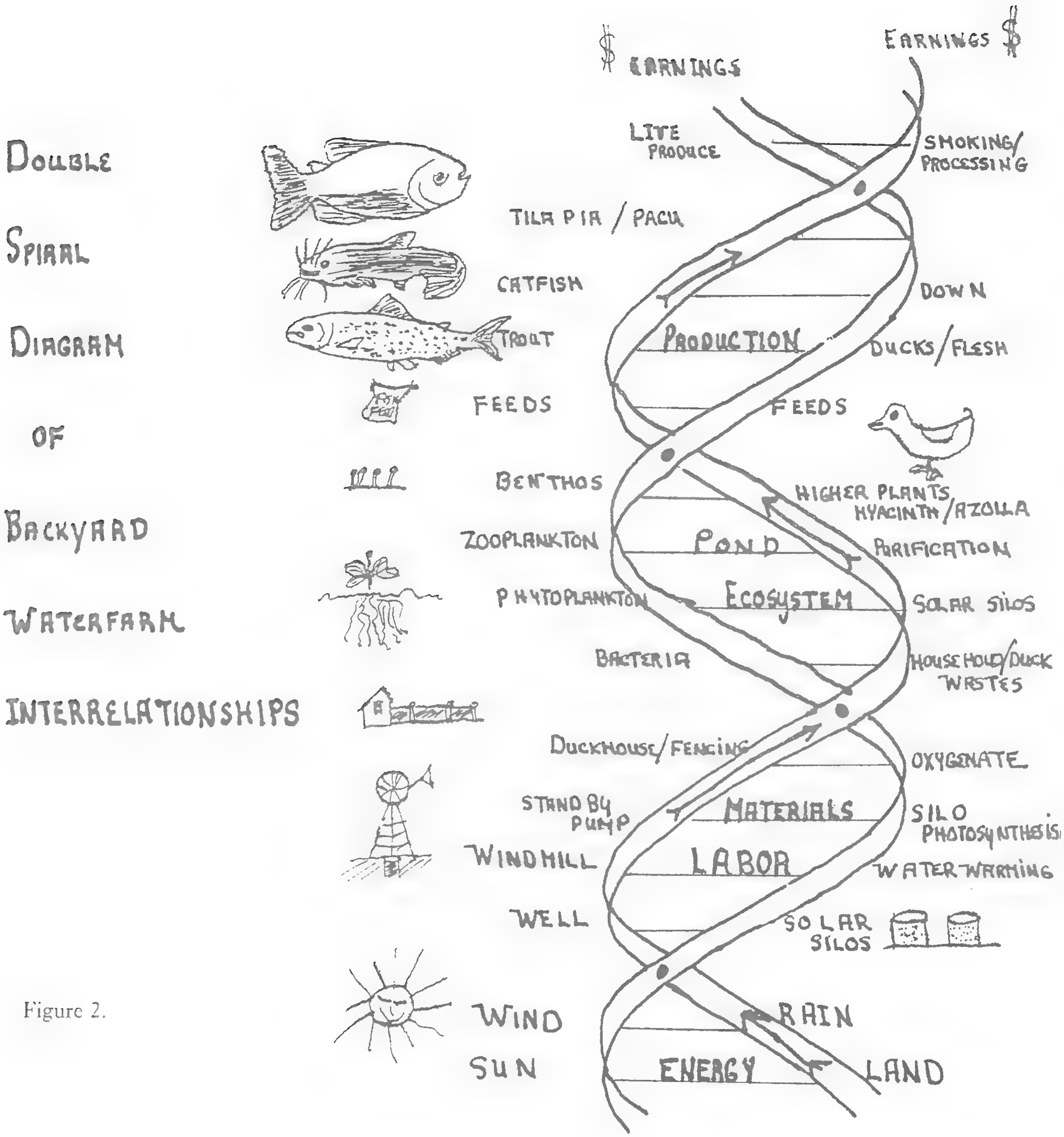


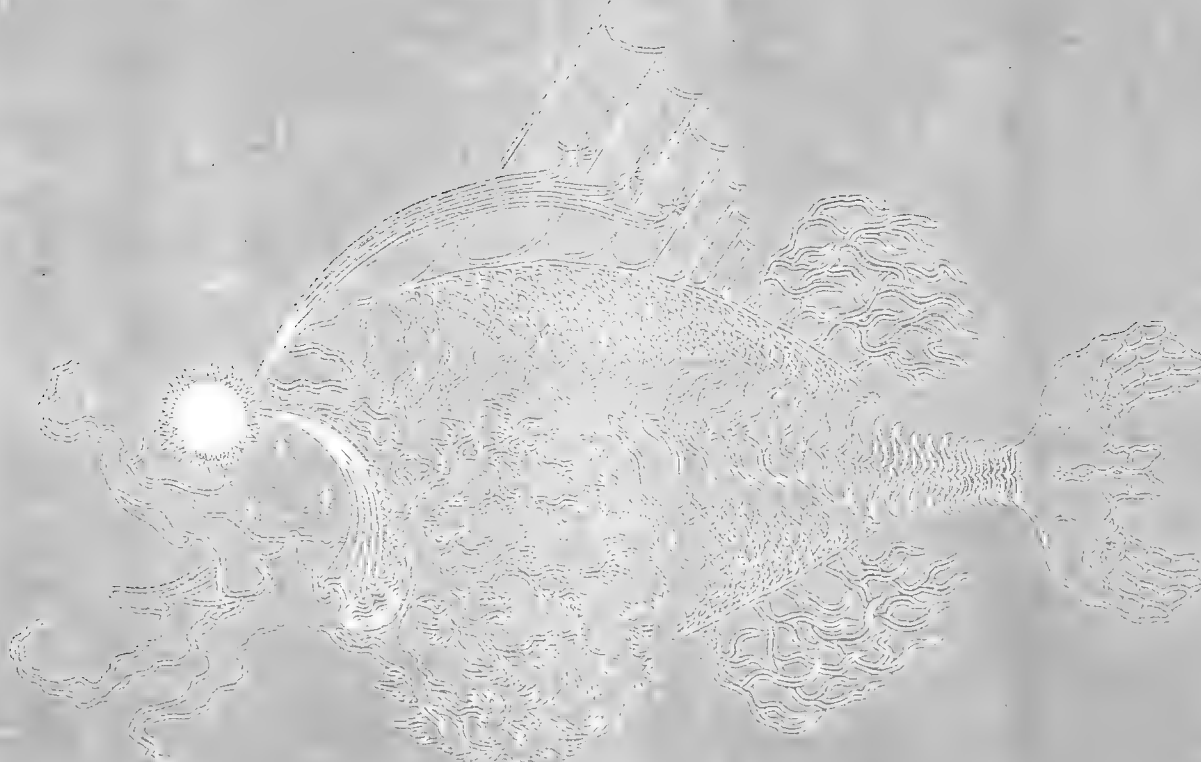
Figure 2.

to be able to sell the crop with minimum effort and transport costs.

For an initial capital investment of $3,950 to $5,800, keeping in mind my backyard already exists, and an annual operating cost of between $1,600 and $2,450, I could realize a net annual return of between $4,783 and $12,967, if the fixed costs were amortized over six years. This would be a family enterprise and friends would help with the harvest, so I shouldn't have labor costs. The water farm could more than pay for itself in its first year.

I know that my farm is still a dream, but with the price of fish climbing, and many people looking for decent quality, poison-free, lovingly grown foods, I think my fantasy is worthwhile. My daughter agrees.

Photo by R. D. Zweig



Bioshelters

This issue, this section is practically as eclectic as New Alchemy itself. Scientific investigation, rigorous measurement and documentation, hands-on working experience, and a certain amount of rather opinionated observation are all included. It is not unedited but, as originally expressed by fourteen Alchies and two Solsearchers, it is virtually unexpurgated. As explained earlier, the Ark was finally completed in early 1977. That gives us, as of this writing, over two full years of experience. As of this writing as well the price of heating oil for the coming winter, has been pegged at ninety cents a gallon. Because of this, we feel a certain urgency to communicate as much as we know about the biologically linked form of solar energy technology that has proved so heartening in the Ark.

The panoply of information to follow is presented in six parts. The first part, by John Todd, who organized, edited and bullied the information out of everyone, recapitulates the rationale and thinking behind the Ark. The second part is a physical description of the building in words and pictures. The drawings we owe to Solsearch Architects and the words are by Ole Hammarlund of Solsearch and John Wolfe, Colleen Armstrong and Joe Seale. The third part is the least technical and I think the most fun with everyone, expert and nonexpert alike, giving voice to what they think about the Ark.

The fourth part describes the working of some of the Ark's subcomponents; the fifth part, the agriculture in the Ark, and the sixth part, the aquaculture. Editorially, as one who didn't chime in about the building in the article, I can only add that I love it. It's beautiful. On a winter day, slipping over ice and frozen ground to go into the Ark and find oneself immersed in warm air, living green and smells of earth and plants, knowing that the small, alive world that greets one exists by virtue of the sun and not irreplaceable fossil fuels, is a joy not easily overstated.

NJT

Photo by Tom Mignone

From Our Experience: The First Three Years Aboard the Cape Cod Ark

By the staff of New Alchemy
& Solsearch Architects

PART 1—THE CAPE COD ARK: ITS RATIONALE REVISITED

John Todd

Since 1971, we have conceived, built and researched eight solar-based structures for culturing diverse foods at New Alchemy.[1] Each has integrated architectural, ecological, agricultural and aquacultural knowledge with solar and wind technologies to create nonfossil-fuel-dependent climatic envelopes for growing food. The bioshelters were vehicles through which we attempted to formulate and test an ecological science of design that we hoped would provide the foundation for a new direction in agriculture.

The need for new directions in North American agriculture has been masked by high productivity. There are, however, hidden costs in orthodox farming: chemical applications add to atmospheric and terrestrial toxicity; cropping regimes, heavy machinery, and herbicides tend to erode soils; capital-intensiveness displaces rural workers and small farmers. Moreover, the general dependence on increasingly scarce substances (natural gas for fertilizer manufacture and petroleulm for fuels, biocides, and transport) and imported materials (Phosphorus, for example) places conventional agriculture in a position especially vulnerable to price hikes, embargoes, or unforeseen market market disruptions.

Implicit in the rise of high-technology agriculture has been the decline of regional food systems. Specialty farms in California, Mexico, and the Great Plains have displaced family agriculture in the Northeast and other less-favored areas. Yet the conditions necessary for such geographic specialization, such as abundant fuels and chemicals, a robust industrial sector, and blithe acceptance of the biological consequences of certain techniques, become less dependable daily.

In view of this trend, a revival of agriculture in the Northeast takes on new plausibility, especially in

[1] *The Book of The New Alchemists*, 1977, ed. N. J. Todd (New York: E. P. Dutton), overviews much of this work.

view of research carried out in the last ten years. For the first time there have come together scientific advances in several diverse fields which, if systematically reorganized into new forms, could revitalize food raising and farming in the region. Advances in ecology, systems theory, materials sciences, microelectronics and computers as well as in the agricultural sciences themselves provide the intellectual underpinnings for ecological design. Food production can be miniaturized, decentralized into densely populated areas and less climatically favored regions, and partially freed of its dependency upon heavy fuel and biocide use. Over the past three years, the bioshelter that we call the Ark has helped us chart such a course.

In 1974/75 we began to conceptualize a bioshelter that would point the way toward a solar-based, year-round, employment-creating agriculture for northern climates. Our goal was to devise a food-raising ecosystem that would use little space and would require roughly one-fifth to one-tenth the

TABLE 1—Bioshelter 1

Structure		
Length	90 ft	(27.43 m)
Maximum width	28 ft	(8.53 m)
Floor area	1,950 ft²	(181.16 m²)
Adjacent aquaculture courtyard (not shown in figure)	1,200 ft²	(111.48 m²)
45° angle south-facing roof	2,000 ft²	(185.80 m²)
Vertical south-facing roof	160 ft²	(14.86 m²)
Translucent ends	320 ft²	(29.92 m²)
Laboratory pedestal	72 ft²	(6.68 m²)
Aquaculture		
Pool	2,872 gal	(10,870 liters)
14 solar ponds in interior	9,100 gal	(34,580 liters)
23 solar ponds in exterior courtyard	15,000 gal	(57,000 liters)
Total solar pond aquaculture facility	24,100 gal	(91,580 liters)

Climate

Air circulation: 3 ft diameter 1 h.p. fan
Hot-air collection—subsoil duct return
Venting: 200 ft² (18.58 m²) on the peak
Plus doors and vents along south side
Hot-air storage (rocks) 43-yd³ (32.88 m³)
Translucent sloping roof
Suspended 5 ft. (1.52 m)
Fiberglass in catenary curve. Double-walled separated by 1″(2.54 cm) air space
Material: Kalwall Corporation Sun-Lite Premium 0.040″ thickness (0.10 cm)
Single-layer ultra-violet transmission: 5% at .33 micron 85% at .38 micron
Visible light transmission: 90+% (.38 .76 microns)
Short-wave infra-red: most transmitted (.76 2.2 microns)
Long-wave infra-red: most blocked and retained in interior (2.2—50 microns)
North walls and roof, ½″ plywood on each side, 6 in. (15.24 cm) fiberglass insulation
Shingled
Foundation insulation: 2 in.: (5.08 cm) styrofoam
Auxiliary heat: none

capital of an orthodox farm. Our original target was for a bioshelter-based microfarm costing $50,000, land included.

Our strategy was to avoid mimicking or scaling down single crop commercial farms. Instead we adopted an ecological perspective, incorporating into the design high levels of integration, a multiplicity of pathways, a blend of soft technologies and mixed crops (including greens, vegetables, flowers, fish and other aquatic foods), and the mass propagation of trees. The structure for the microfarm was to be a solar building with internal climate and disease and pest controls carried out by ecological, structural and data-processing subcomponents.

The illustrations and photos in the following sections depict the interior of the Ark including the solar-algae pond aquaculture and the light reflecting courtyard in winter. Table 1 provides specifications, size and capacity of the solar structure.

The Ark was a collaborative design effort between Solsearch Architects and The New Alchemy Institute. The sun provides all of the heating. In 1978, a stand-by stove was removed after the bioshelter managed to thrive through two relatively harsh New England winters. Heat is stored mainly in the translucent aquaculture ponds. A 43 cubic yard rock-storage/hot-air system provides short-term heat storage and thermal regulation.

The west end room of the bioshelter houses the interior aquaculture facility of nine solar-algae ponds. Five additional ponds are located in the central agricultural zone.

Next to the aquaculture room is the rock-storage area and a 2,872 gallon (10,870 liter) sunken fish-culturing pond, which also serves as a source of nutrient-enriched irrigation water. On top of the rock storage is an experimental vine crop area. Behind it stands a micro-computer encased in a humidity-controlled, glass-fronted housing. Above this is a small laboratory suspended from the vault of the structure.

The central area is agricultural, and is used to evaluate food crops suited to such a solar climate. In this section varietal testing of marketable crops is carried out on four tiers. Against the south wall is a long bench area used for the mass propagation of tree, flower and vegetable seedlings. In light-limited zones, small micro-control ecosystems, or biological "islands," have been established as habitats for organisms that pollinate crops and control crop pests. Deep enriched soils are used as the growing medium as well as for gas production, particularly carbon dioxide.

The eastern end of the structure includes a work area and a production bed for vine crops such as tomatoes.

There are many linkages between the aquaculture and agriculture. The fish tanks provide irrigation water and nutrients in the form of fish feces and dead

algae to the crops while weeds, cuttings, and agricultural by-products are in turn often employed as fish feeds, comfrey being a prime example of this.

Such a prototype microfarm differs from existing greenhouse facilities in several fundamental ways, including:

1. Solar heating instead of conventional fossil fuel systems, which account for more than 50% of food-raising costs in cold climate greenhouses;[2]
2. Heat storage utilizing the fish culture facilities as well as a subterranean rock-filled chamber;
3. The use of warmed aquaculture water containing nutrients for irrigation and fertilization, eliminating the need for most purchased fertilizers;
4. Using terrestrial plant wastes as feeds for fishes and indigenous culture of feed stocks for the fishes, particularly algae but also zooplankton;
5. Using algae-filled solar ponds that operate as solar heat collectors as well as fish culture components;
6. The integration of aquaculture with greenhouse plant-raising components employing Chinese polyculture strategies in the former and ecological, multi-story design in the latter;
7. Pest control through such biological pathways as lizards and insects that are predatory on pest species;
8. Emphasis on investigating food plant species and varieties adapted to natural interior climatic variations as an alternative to energy expensive climatic manipulation;
9. The eventual use of an integral windmill-powered freezing and food-storage plant; and
10. A structure that utilizes insulated north walls and roof and reflective interior walls to re-radiate light from the sun and southern sky onto the growing area, so as to conserve heat without seriously reducing the light available for plants.[3]

The Ark shares a number of characteristics with orthodox greenhouses and cultivation practices, including:

1. Plant propagation and culture techniques;
2. Soil moisture control through irrigation;
3. Humidity control and air circulation to lessen disease;
4. Disease-resistant varieties;
5. Intensive planting and management techniques; and
6. Experimentation in one section of the bioshelter with the most valuable crops commercially, including tomatoes, cucumbers and lettuce.[4]

Three years of research have so far done much to vindicate the bioshelter concept. Ecological stability and disease- and pest-control have been achieved without recourse to biocides. The agricultural/aquacultural environments have proven productive. The aquaculture has achieved the highest yields of any standing body of water yet described. We have grown valuable cash crops to maturity in winter and identified a number of food crop varieties adapted to the bioshelter solar environment. We have started work on a micro-control ecosystem and biological management program. Unquestionably, our ecological and "space ship" approaches to food culture are showing evidence of viability.

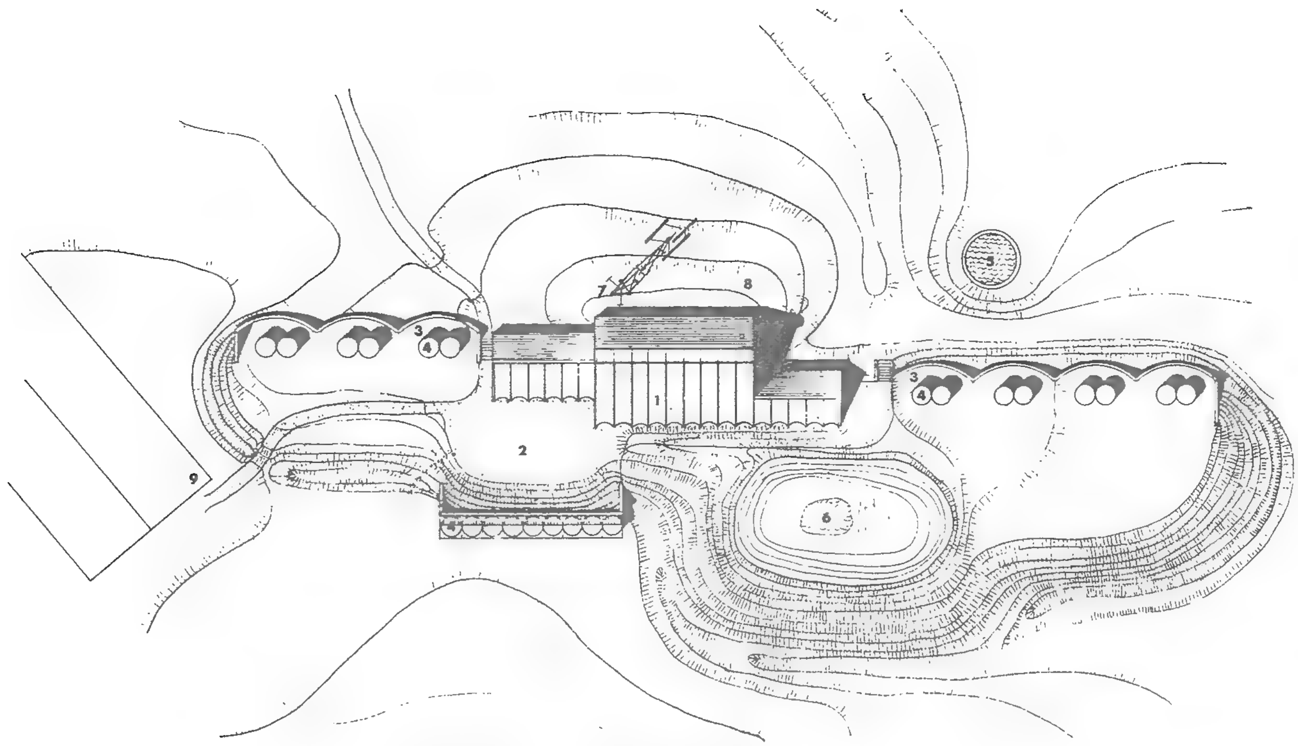
As a consequence of working with the Ark we are now reaching a new plateau, namely, the synthesis of economics with an ecological design science. We seek to bring together ideas of earth stewardship, food growing and the creation of exciting new ways of making a living. I believe that such a fusion is now possible.

I hope the following sections chronicling our experiences will cause you to consider the bioshelter as a way of feeding family and friends or as a livelihood in the future.

[2] D. G. Dalrymple, 1973, "Controlled Environment Agriculture." USDA Economic Research Report #89: 63–68.

[3] T. A. Lawand et al., 1975, *Solar Energy*, 16: 307–12.

[4] D. G. Dalrymple, loc. cit.



EXTERIOR LANDSCAPING

PART 2--PHYSICAL DESCRIPTION OF THE ARK

Drawings of the Ark by Solsearch Architects

Building the Ark: A Brief Overview

Ole Hammarlund

Work on the Ark began as soon as the funding was assured, which happened to be January. After a month of design we were ready to start building. The weather on the Cape is not really suitable for outside work in the winter, but the frost is not too deep and our resourceful excavating–concrete contractor Ted Wolfe had no trouble digging for the footings. Pouring was more of a problem. The weather had to be warm enough to prevent the concrete from freezing, yet cold (or dry) enough to permit the concrete truck access through the field. One winter morning looked right and we started, but two hours later, three trucks were stuck in the mud and Ted and I chopped practically every tree in sight and threw the branches under the muddy wheels.

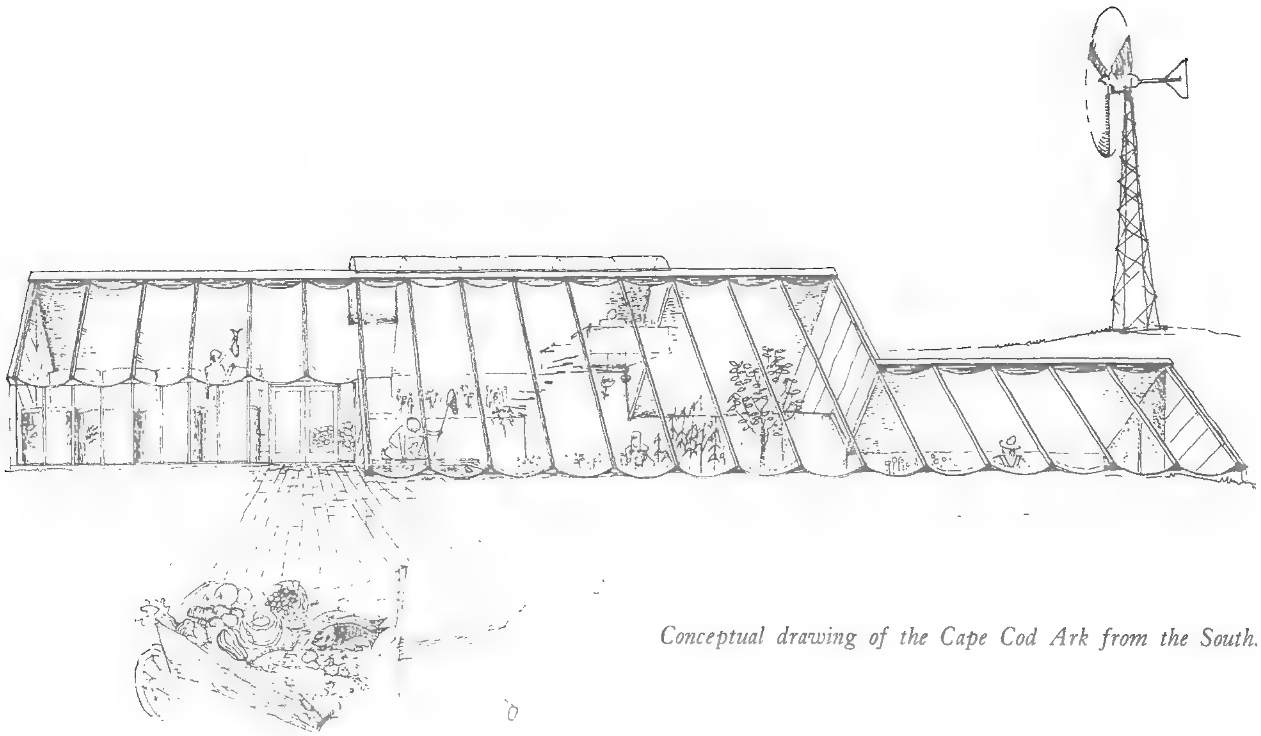
Hours later we had succeeded in moving all the trucks and pouring the concrete. We were ready to start framing as soon as the forms were stripped.

The work force for the Ark consisted of myself, in charge of on-the-spot designing, work coordination and getting materials, and the crew of New Alchemists, taking time off from their regular chores, as well as skilled and unskilled volunteers for the day or week.

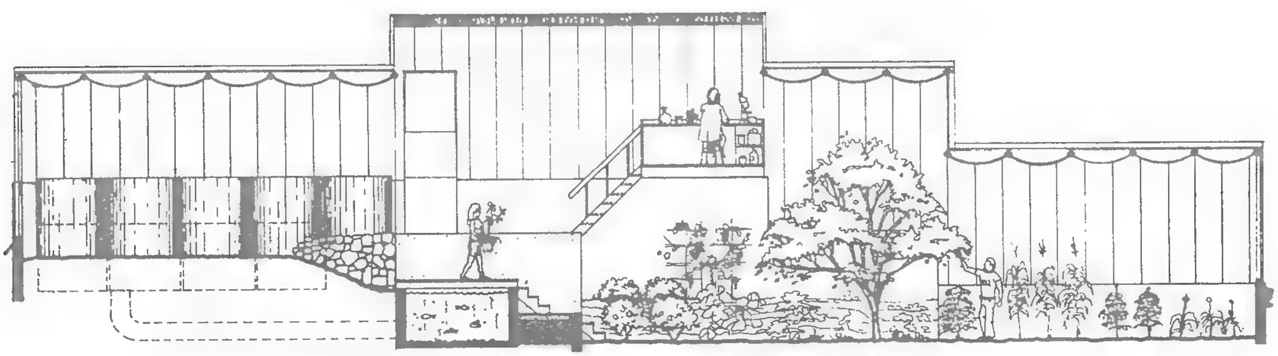
Some sections of the roof were prefabricated on the ground and raised with a great crew of Saturday visitors. Other sections were built by two carpenters from Lindisfarne. Meanwhile, in the barn, I was preparing for the prefabrication of the curved double-glazing panels. The first step was the production of a 22′ long and 4½′ wide curved mold. In that mold the two layers of Kalwall fiberglass would be riveted onto ¾″ U channels creating the insulating airspace between. On one side of the panel the 2″ x 2″ rafter would be mounted with a 1″ x 2″ coverplate. On the other side a 1″ x 3″ coverplate was fastened. Upon erection just one row of screws would fasten all the panels together into a strong, integral roof system.

On D-day we were a crew of six suspended from ladders reaching from the ground to the peak. It was incredible how the wobbley panels became stiff when mounted together. When I drove home in the night after installing the last panel, I was considering eliminating a truss supporting the panels at midpoint. What folly! The next night a gale rose, and I was called to the site to find most of the long, glazed panels caved in. The welds in the top brackets had failed causing the now unsupported 2 x 2 rafter to collapse.

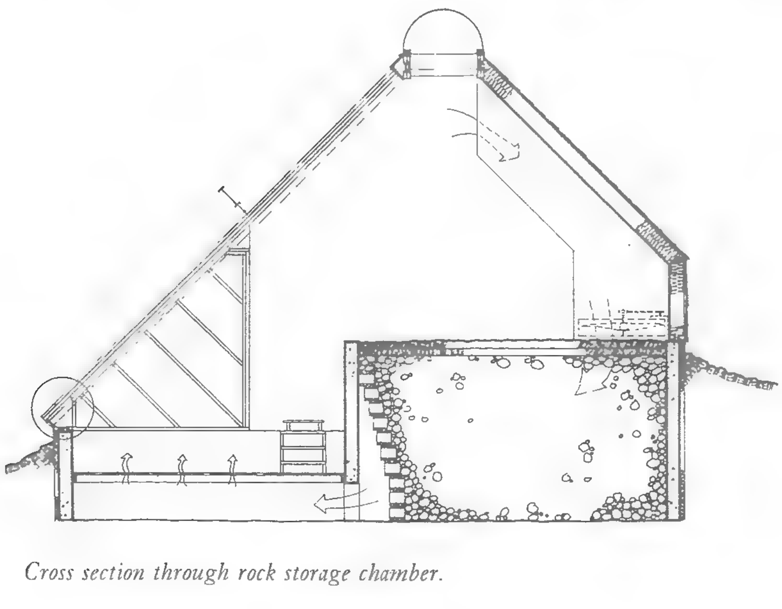
It took several weeks to replace the damaged panels, this time well-supported at midpoint. About this time, Peter Laue took over my role. All the beautiful finishing work is his creations, done during the following year.



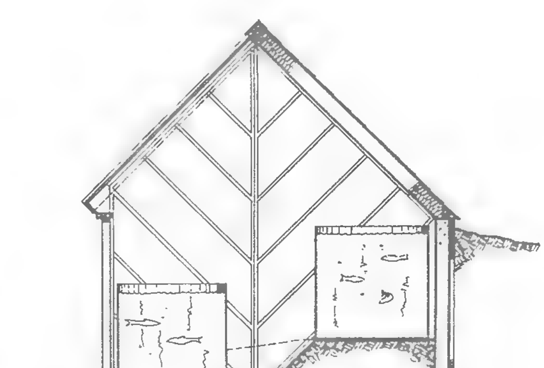
Conceptual drawing of the Cape Cod Ark from the South.



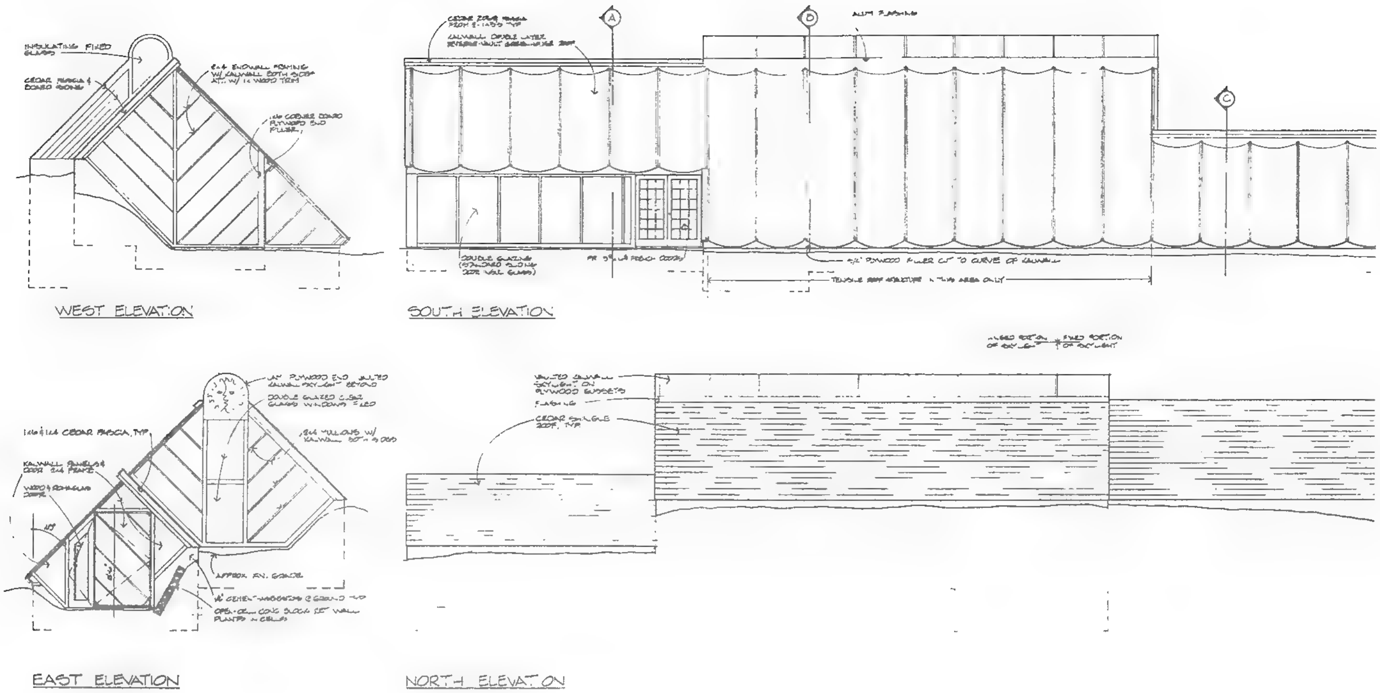
The Ark interior.



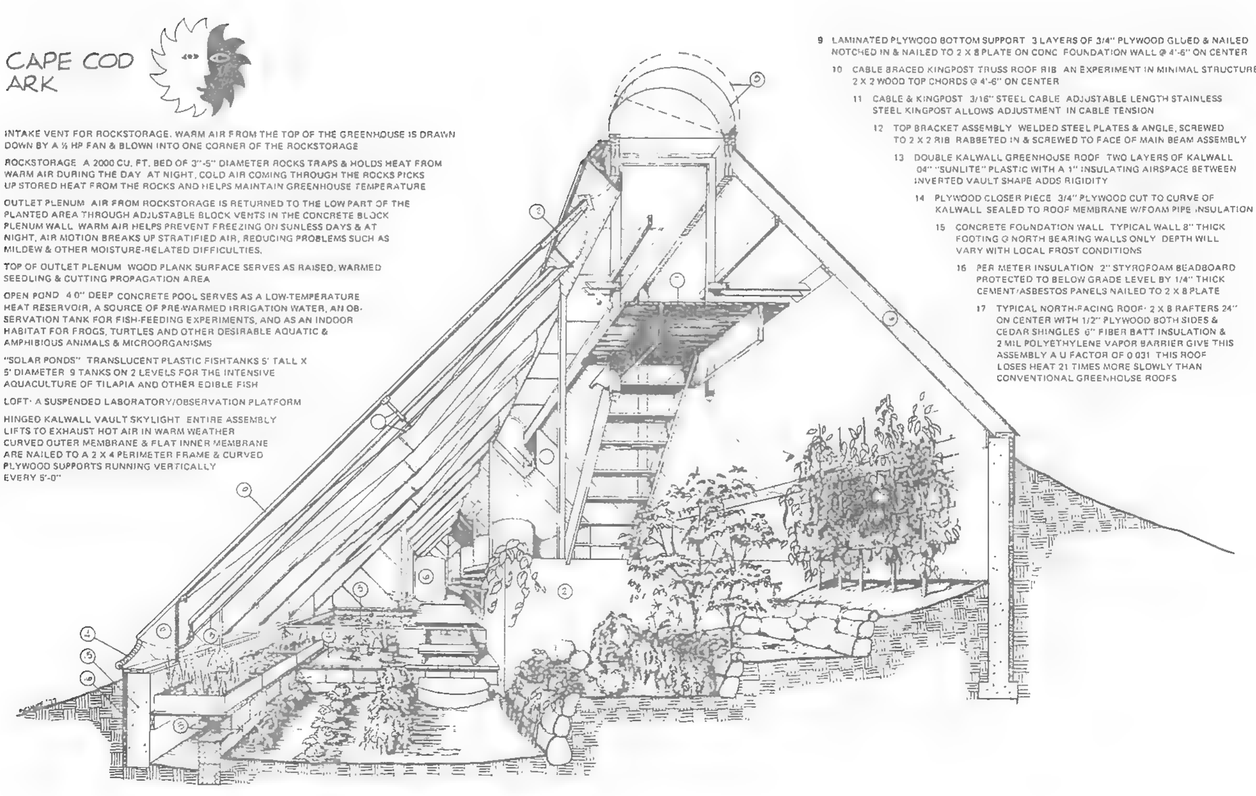
Cross section through rock storage chamber.



Cross section through aquaculture room.



CAPE COD ARK



1 INTAKE VENT FOR ROCKSTORAGE. WARM AIR FROM THE TOP OF THE GREENHOUSE IS DRAWN DOWN BY A ½ HP FAN & BLOWN INTO ONE CORNER OF THE ROCKSTORAGE

2 ROCKSTORAGE A 2000 CU. FT. BED OF 3"-5" DIAMETER ROCKS TRAPS & HOLDS HEAT FROM WARM AIR DURING THE DAY AT NIGHT, COLD AIR COMING THROUGH THE ROCKS PICKS UP STORED HEAT FROM THE ROCKS AND HELPS MAINTAIN GREENHOUSE TEMPERATURE

3 OUTLET PLENUM AIR FROM ROCKSTORAGE IS RETURNED TO THE LOW PART OF THE PLANTED AREA THROUGH ADJUSTABLE BLOCK VENTS IN THE CONCRETE BLOCK PLENUM WALL WARM AIR HELPS PREVENT FREEZING ON SUNLESS DAYS & AT NIGHT, AIR MOTION BREAKS UP STRATIFIED AIR, REDUCING PROBLEMS SUCH AS MILDEW & OTHER MOISTURE-RELATED DIFFICULTIES.

4 TOP OF OUTLET PLENUM WOOD PLANK SURFACE SERVES AS RAISED, WARMED SEEDLING & CUTTING PROPAGATION AREA

5 OPEN POND 4 0" DEEP CONCRETE POOL SERVES AS A LOW-TEMPERATURE HEAT RESERVOIR, A SOURCE OF PRE-WARMED IRRIGATION WATER, AN OBSERVATION TANK FOR FISH-FEEDING EXPERIMENTS, AND AS AN INDOOR HABITAT FOR FROGS, TURTLES AND OTHER DESIRABLE AQUATIC & AMPHIBIOUS ANIMALS & MICROORGANISMS

6 "SOLAR PONDS" TRANSLUCENT PLASTIC FISHTANKS 5' TALL X 5' DIAMETER 9 TANKS ON 2 LEVELS FOR THE INTENSIVE AQUACULTURE OF TILAPIA AND OTHER EDIBLE FISH

7 LOFT· A SUSPENDED LABORATORY/OBSERVATION PLATFORM

8 HINGED KALWALL VAULT SKYLIGHT ENTIRE ASSEMBLY LIFTS TO EXHAUST HOT AIR IN WARM WEATHER CURVED OUTER MEMBRANE & FLAT INNER MEMBRANE ARE NAILED TO A 2 X 4 PERIMETER FRAME & CURVED PLYWOOD SUPPORTS RUNNING VERTICALLY EVERY 5'-0"

9 LAMINATED PLYWOOD BOTTOM SUPPORT 3 LAYERS OF 3/4" PLYWOOD GLUED & NAILED NOTCHED IN & NAILED TO 2 X 8 PLATE ON CONC FOUNDATION WALL @ 4'-6" ON CENTER

10 CABLE BRACED KINGPOST TRUSS ROOF RIB AN EXPERIMENT IN MINIMAL STRUCTURE 2 X 2 WOOD TOP CHORDS @ 4'-6" ON CENTER

11 CABLE & KINGPOST 3/16" STEEL CABLE ADJUSTABLE LENGTH STAINLESS STEEL KINGPOST ALLOWS ADJUSTMENT IN CABLE TENSION

12 TOP BRACKET ASSEMBLY WELDED STEEL PLATES & ANGLE, SCREWED TO 2 X 2 RIB RABBETED IN & SCREWED TO FACE OF MAIN BEAM ASSEMBLY

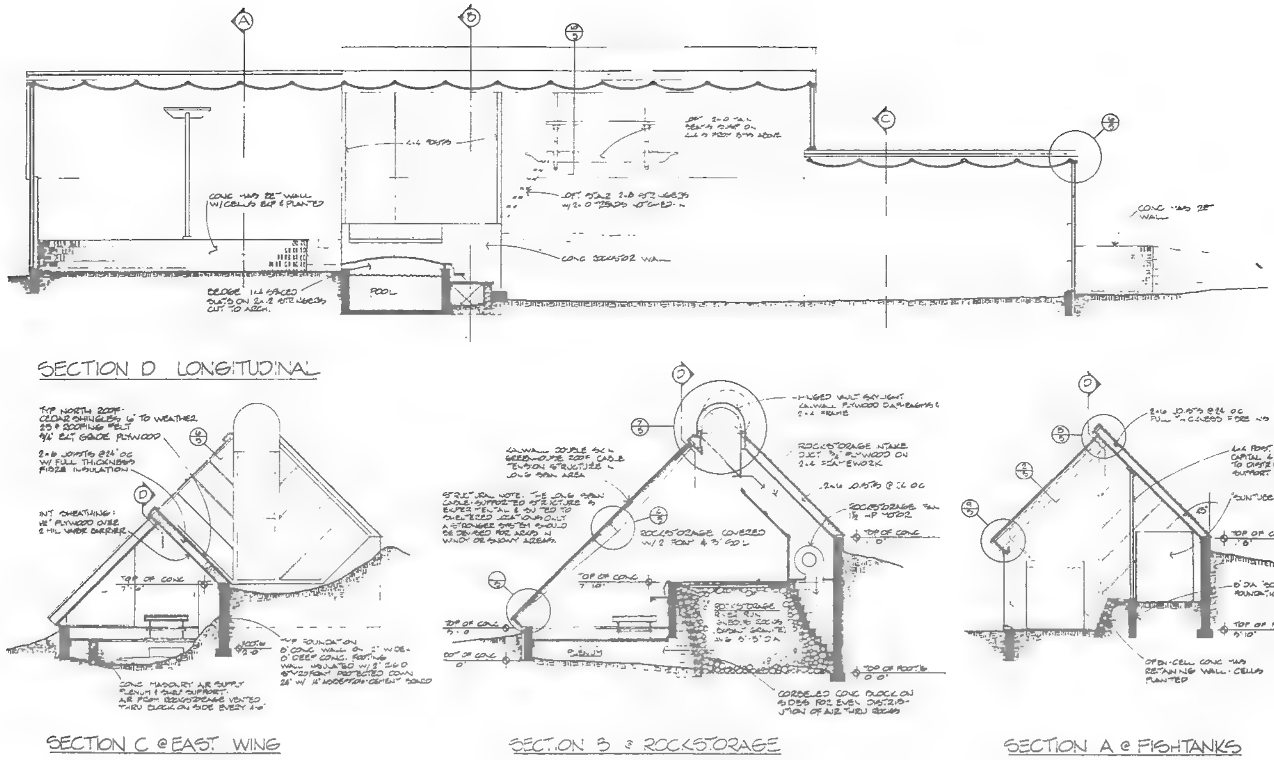
13 DOUBLE KALWALL GREENHOUSE ROOF TWO LAYERS OF KALWALL 04" "SUNLITE" PLASTIC WITH A 1" INSULATING AIRSPACE BETWEEN INVERTED VAULT SHAPE ADDS RIGIDITY

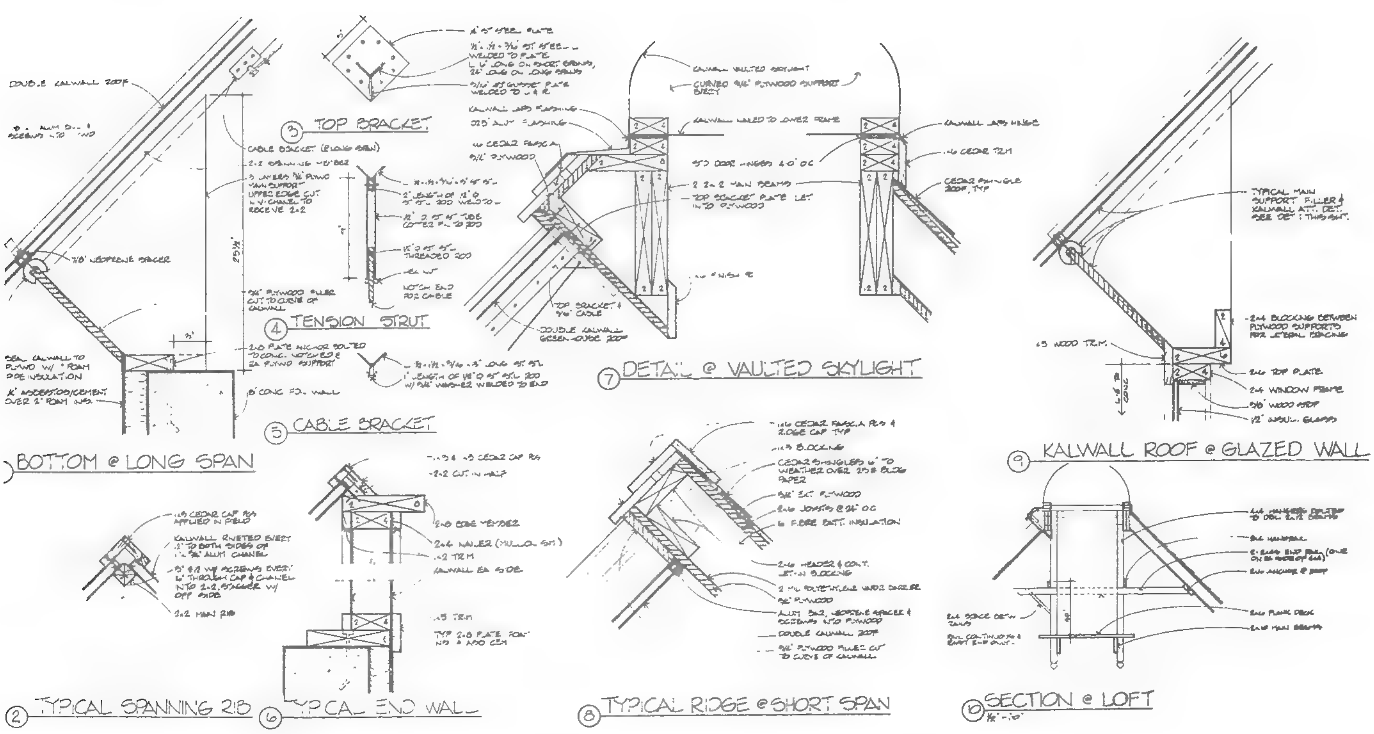
14 PLYWOOD CLOSER PIECE 3/4" PLYWOOD CUT TO CURVE OF KALWALL SEALED TO ROOF MEMBRANE W/FOAM PIPE INSULATION

15 CONCRETE FOUNDATION WALL TYPICAL WALL 8" THICK FOOTING @ NORTH BEARING WALLS ONLY DEPTH WILL VARY WITH LOCAL FROST CONDITIONS

16 PER METER INSULATION 2" STYROFOAM BEADBOARD PROTECTED TO BELOW GRADE LEVEL BY 1/4" THICK CEMENT/ASBESTOS PANELS NAILED TO 2 X 8 PLATE

17 TYPICAL NORTH-FACING ROOF· 2 X 8 RAFTERS 24" ON CENTER WITH 1/2" PLYWOOD BOTH SIDES & CEDAR SHINGLES 6" FIBER BATT INSULATION & 2 MIL POLYETHYLENE VAPOR BARRIER GIVE THIS ASSEMBLY A U FACTOR OF 0 031 THIS ROOF LOSES HEAT 21 TIMES MORE SLOWLY THAN CONVENTIONAL GREENHOUSE ROOFS


SECTION D LONGITUDINAL
SECTION C @ EAST WING
SECTION B @ ROCKSTORAGE
SECTION A @ FISHTANKS


3 TOP BRACKET
4 TENSION STRUT
5 CABLE BRACKET
BOTTOM @ LONG SPAN
7 DETAIL @ VAULTED SKYLIGHT
9 KALWALL ROOF @ GLAZED WALL
2 TYPICAL SPANNING 2:8
6 TYPICAL END WALL
8 TYPICAL RIDGE @ SHORT SPAN
10 SECTION @ LOFT

Changes in the Ark Since Building

The Ark is constantly evolving and being improved. The following changes have improved its effectiveness as an agricultural bioshelter.

John Wolfe

Since the completion of the Ark any changes have been minor. In January of 1977, we boldly decided to remove the woodstove which was the back-up heat source. During the summer of 1978, two skilled friends, John Jennings and Christian Jacqz, installed a 7′ by 7′ triangular vent overlooking the sunken pond, thereby improving air circulation. For the winter 1978/79 season we added five single-glazed, 630 gallon solar-algae ponds to the building.

A smattering of additional modifications are imminent. We surmise that the area below the southern glazing bleeds heat more quickly than we'd like. The plywood soffits at the base of the curved fiberglass panels need an inch of board insulation, and the hot-air duct running from the rock bin along the south foundation wall needs its inner wall and floor lined with board insulation as well. Kathi Ryan would like to see still a little more overall summer ventilation and winter air movement for the high northern tier of growing beds. One or two more vents will help to bring the vent-area-to-air-volume ratio close to the breezy and cooler Six Pack, and boring a hole into the side of the rock box to short circuit some of the forced air will solve the latter problem.

During the autumn preparations, tropical aquaculture and temperate agriculture seem at cross purposes. Warm-weather crops need sustaining well into the fall and Ark temperatures approach these plants' upper tolerances. We plan to test a new fan and vent strategy, controlled by thermostats or the Microlog computer. The fan will start drawing hot air into storage when low air temperatures reach 72°F. (upper air would be 80°); if this doesn't keep air temperatures cool enough, venting will be activated at 77° as a last resort. If the aquaculturists want to store still more heat in the ponds than these elevated temperatures permit, we may temporarily partition off the west wing which holds nine solar-algae ponds (a total of about 5,700 gallons or 21.6 cubic meters of water), and virtually simmer the aquaculture area in late August, September and October.

These nine solar-algae ponds act not only as fish culturing units, but also as passive solar collectors with internal heat storage. Daily wintertime temperature fluctuations in the ponds provide some indication of the amount of heat that is stored and later released. Amplitudes in temperature oscillations averaged at least 2½°C. this past winter. Since the ponds contain 2.3 to 2.5 cubic meters of water, this represents six million calories absorbed, stored and released by each pond over an average 24-hour period. Over four winters this heat will equal the amount of energy expended in manufacturing the pond (calculations are detailed in the Aquaculture section). Over the expected lifetime of the pond, five times as much useful energy will be generated than was spent in its creation.

Colleen Armstrong

Looking at the Ark in theory and design, most of the changes that have taken place are secondary. Besides removing the rusty potbelly stove (where little beasties habited), incorporating additional solar-algae ponds, and maintaining the building itself, various wood constructions have increased the Ark's value as a functional bioshelter.

In the summer months, the west wall along the sunken fish pond can be replaced by a screen duplicate. With this screen wall and after opening the east end doors, a stream of crosswinds can pass through the growing area. Consequently, the high temperatures inside drop a few degrees and the plants benefit from the extra aeration. Many efforts have been made to optimize the vertical space within the building. Crops are grown on trellises that can be removed when unnecessary. Wooden struts have been attached to the support beams where hanging pots are suspended. Large boxes placed on top of the rock storage area have been filled with composted soil and various crops have been grown within. This particular growing area is special because the soil absorbs some of the heat given off by the rock storage and the area itself is the warmest and brightest in the Ark. Tree cuttings, large herb plants and tropical vegetation have all been successful in this warm zone.

How the Building Works

Joe Seale

The Ark is a solar-heated, windmill-assisted bioshelter which functions year-round without fossil fuel or auxiliary heating. It employs electricity in an air-circulating fan, a microcomputer and for the nocturnal aeration of its aquaculture facilities. Our present design emphasis is toward the reduction of the Ark's electrical needs. Happily, the solar performance of the building has exceeded our expectations.

The summer functions of the Ark are less critical than those of winter. Light is abundant in summer, although much of the light comes from the east and west. In addition to the south glazing, the Ark's east and west windows are important to its summer functioning. The only potential climate problem is over-

heating, and the antidote is ample ventilation.

The architectural requirements posed by winter are more demanding. Sunlight comes in at low sun elevation angles for a shorter period of the day from the southeast to the southwest. The photosynthesis by plants and algae as well as the maintenance of warmth rely on the light-gathering capability of the building. The steep pitch of the south glazing reaches up to catch near-horizontal rays of the sun effectively. A white back wall reflects incoming light down onto the plants and the solar-algae ponds. Marble chips in front of the Ark reflect light up into the building.

Such a climatic envelope has to retain the heat of the incoming sunlight. Sufficient air-tightness helps, and some doors are taped shut for the winter to cut infiltration. Double glazing on the windows and a second layer of Kalwall for the south aperture create dead air spaces for further insulation. The north side of the building, which sees little light, is opaque and heavily insulated. In our case, very heavy insulation does not pay, as glazing heat losses dwarf small gains to be made through extra north-side insulation. Insulating skirts penetrate down into the soil around the building periphery to retard heat loss.

To avoid plant-stressing temperature fluctuations, and particularly to avoid freezing temperatures at night and in cloudy weather, heat storage must complement good heat retention. The structure itself provides some inherent heat storage in the thermal mass of concrete walls, soil, etc. But the bulk of the thermal mass comes from the solar-algae ponds and a rock storage bin.

The rock storage bin uses a blower to draw air from near the ceiling, force the air through a rock pile, then out through ducts at floor level. The rocks absorb daytime warmth from the air, retain it, and give up that warmth as the building cools at night and in cloudy weather. Besides storing and relinquishing heat to reduce temperature fluctuations, the rock storage system provides important air movement necessary 1) for healthy plant growth without excessive mold and fungus problems, and 2) for disrupting the stratification of cold air that can otherwise collect in low places and even cause frost damage under extreme conditions.

The solar-algae ponds complement the rock storage. They absorb heat by air convection, infra-red absorption from warmed surfaces in the building, and by absorption of direct and reflected sunlight. They give up heat by convection and infra-red radiation. Water is a very effective heat absorber, three times as effective by volume as broken rocks. And the solar-algae ponds serve a dual economic function as thermal reservoirs and as spaces to raise fish. While the thermal functions of the solar-algae ponds require no direct input of mechanical energy, the rock storage air circulation helps make the solar-algae ponds work more effectively by breaking thermal stratification and enhancing convective heat exchange to the ponds. If more ponds were to replace the thermal mass of the rock storage system, mechanical blowers of some sort would still be necessary, although total mechanical energy consumption could be reduced substantially.

The cycling of water vapor through the Ark introduces a factor whose climatic and biological consequences we are just beginning to understand. When air temperatures exceed about 20°C. (68°F.) the thermal energy lost in the water vapor carried by escaping air can (depending on indoor and outdoor temperature and relative humidity) equal or exceed the thermal energy lost in the dry air itself. Therefore, daytime ex-filtration of water vapor can represent a significant net heat loss. That loss is felt selectively by surfaces of evaporation: the solar-algae ponds, leaves, and wet soils. Condensation on glazings reduces their effective thermal resistance. Consider the heat loss on surfaces of evaporation. That heat of vaporization reappears with condensation on the glazing surfaces and is conducted to the outdoors. The warming of inner glazing surfaces by water condensation reduces convective heat loss to those surfaces, but in a total accounting the building loses more heat. Condensation on glazings in a bioshelter at certain times is practically inevitable, so condensed water must be channeled and kept from surfaces it might damage. After the initial evening chill has condensed most of the water out of the air in the Ark, water vapor almost ceases to affect thermal energy transport.

An article in the fifth *Journal*, "A Thermal Budget for the Greenhouse of the Ark on Prince Edward Island: Where Does All The Heat Go?" gives a quantitative analysis and time domain simulation of the thermal energetics of the P.E.I. Ark. A similar model for the Cape Cod Ark is being undertaken.

Photo by John Todd

PART 3—CRITIQUE OF THE ARK: *FOURTEEN NEW ALCHEMISTS AND THE TWO ARCHITECTS REPORT ON THEIR IMPRESSIONS AFTER THREE WINTERS OF ARK PERFORMANCE*

New Alchemy: Colleen Armstrong, Denise Backus, Earle Barnhart, Al Doolittle, David Engstrom, Tanis Lane, Conn Nugent, Jeff Parkin, Kathi Ryan, Robert Sardinsky, Joe Seale, John Todd, John Wolfe, and Ron Zweig

Solsearch Architecture: David Bergmark and Ole Hammarlund

Questions asked by John Todd.

Here those of us most closely associated with the Ark tell of our experiences and our concerns about the bioshelter. We also try to explore the deeper meaning of the Ark and its place in the future. Any redundancy between us has been retained to indicate those areas where agreement is strong. No comments have been deleted so the full range of feelings is expressed.

Section 1: Bitches, Suggestions and Changes

A. What Do You Think Is Most Wrong With the Ark?
B. How Would You Correct It?

Colleen:

A. The biggest problem is proper ventilation. Especially in summer months, we have seen unhealthy temperature extremes over the past two years. As much as 40°F. in one day. Adequate ventilation would provide a steady current of air at all levels inside the Ark. Plants would be hardier; there would be less stagnant air and better cross-pollination. Cooler, stabler air temperatures would facilitate the summer growing regime.

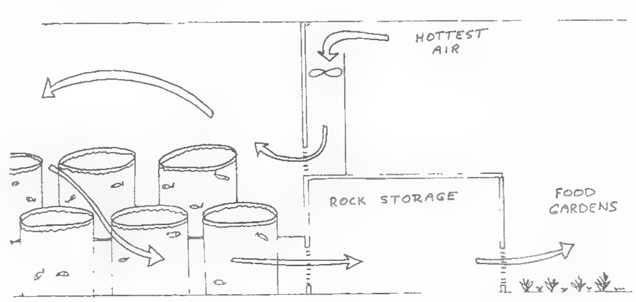
B. Top vents that covered the entire growing range and side vents like those in the Six Pack (a smaller bioshelter at N.A.I.) would be a start. Automatic ventilation would be a consideration. The motors are not that large and there are many on the market that are quite dependable. Although I hate to admit it, these little mechanisms are more responsive than some of the Ark keepers, i.e. Me.

Earle:

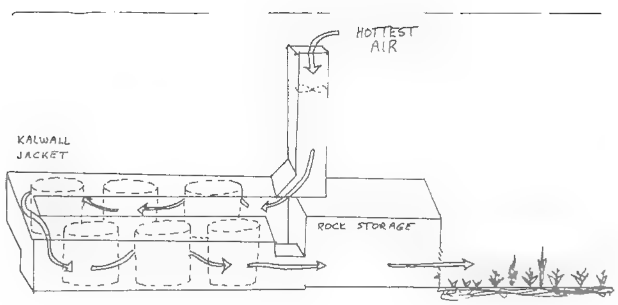
A. The active heat distribution with the fan is now functionally separate from the heat retained with the aquaculture water. The major management hassle has been that the gardeners want to vent excess heat in the spring and fall, while the aquaculture people want to absorb heat in the spring and fall. There is now no structural way to transfer heat, except by letting the internal temperature rise and passively heat the fish ponds.

B. Alter active distribution to place excess heat from the air directly into the aquaculture water.

Solution 1: Separate the aquaculture section from the main plant growing zones. First send solar heated air to the aquaculture room, to return by flowing through a new opening in the rock storage area (see the following sketch).

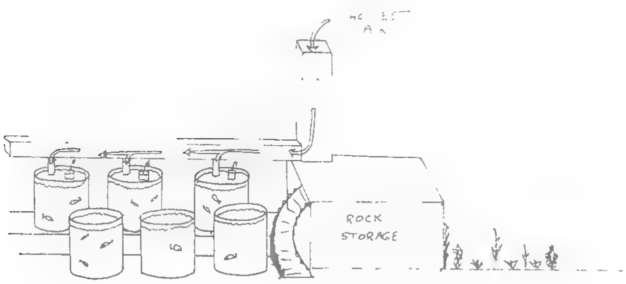


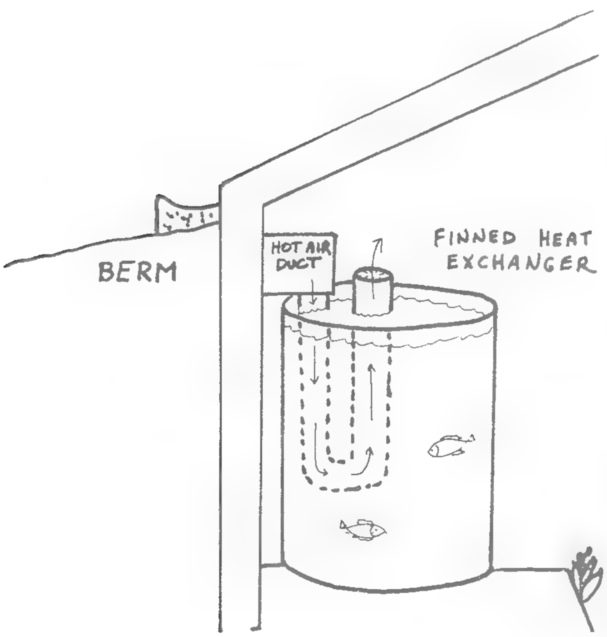
Solution 2: Put a Kalwall jacket around the aquaculture tanks. This jacket need not be totally air tight, and will also act as night insulation. It can be



made to be removable (see the above sketch). This is functionally a good solution, but with many drawbacks, including difficult access.

Solution 3: Hot air is channeled to ponds in ducts, and passed through finned tubes in each tank, in order to transfer heat directly into the water (see the following sketches for detail).





David B.:

A. I happen to have a rather soft spot for the Cape Cod Ark over and above the other buildings we have designed and built. So what's *most* wrong with the Ark: It is a "one-of-a-kind" structure, simple in theory and construction, but too difficult to duplicate in its present form and/or increased scale. The components of the building—north wall, tensioned structural members, the glazing panels—are themselves too sophisticated (perhaps unnecessarily) for conventional home-built or factory-built greenhouses.

B. I would advocate a simpler building systems approach. We've become increasingly excited about conventional systems which have been available on the market for some time, for example, double-film greenhouses using double polyvinyl-fluoride instead of fiberglass, with insulation curtains and back-up wood heat. Heat stretched P.V.F. (Tedlar) has been catching our eye, as well, because it can be used as a durable glazing system (high light transmissions and higher R-factor) as the north insulation wall with insulation placed between Tedlar sheets.

Al:

A. The double .040″ glazing Kalwall on the south wall is too much. It possibly needs some transparent material. The building is too noisy, and the sounds are wrong for this building.

B. If we were using Kalwall I would try a single layer of .040″ with a thin layer of either 0.025″ or some other material.

David E.:

A. One shortcoming is the exterior caulking and finishing in the Kalwall areas. Silicone sealant was used and has peeled over most of the surfaces in contact with Kalwall. The boards lapping over the Kalwall are untreated wood and consequently poor adhesions. As a

Photo by John Todd

result east and west ends of building look sloppy.

B. Use high-grade wood—spruce rather than pine—with urethane on areas of glue contact. Also the Kalwall areas in contact with the wood should be sanded and properly prepared for flue adhesion.

Ole:

A. The internal air change speed is too slow. I'm not happy with the low inlets for natural ventilation.

B. A low static pressure, high volume fan would be. The problem with the low inlets has been partially corrected by summer screen panels.

Conn N.:

A. The problems I see with the Ark are bad venting, an inefficient use of space, some poor workmanship, and difficult fabriations such as the concave Kalwall.

Jeff:

A. I feel the Ark should and could be a much more sensuous experience. To catalyze people's awareness of the fulfillment possible in nurturing ecosystems, the root of that timeless organic bond between people and nature should be the primary focal point.

B. Perhaps grow as wide a variety of flowers as possible for both visual and aromatic contributions.

We could incorporate into some utilitarian functions, some falling water (i.e. a small waterfall). The sound of this with that of bees, maybe some birds, and silence would help to say it. I would somehow minimize the noise generated by the fan. The appearance of lushness should be kept at a maximum, even if this means the introduction of some nonutilitarian plants. Hanging and/or climbing plants would add a lot to this.

Even when immersed in the interior of the Ark, one should not lose touch with the outside world. Transparent glazing (portholes if you like) should be interspersed with the translucent so that the sky and rest of the surrounding environment is visible from many places inside although some balance would have to be achieved with one's need for privacy. The transparent southern vertical windows serve only a token function in this sense.

Kathi:

A. To retain as much heat as possible there are no windows in the north roof and walls. This can create some difficulties with the agriculture. I've noticed that the plants grown on the upper levels of the Ark are extremely *phototropic,* often spindly. The flowering and fruiting plants tend to produce a lot of foliage but often few flowers or fruit. In the design there was a laboratory deck at the top of the building directly over the northwest section of the growing area: The incoming light that would normally be available to those plants was blocked.

B. The lab is not essential to the function of the greenhouse and should be omitted from future designs. We are now using the area below the lab for two large solar tanks and have dismantled parts of it to allow more light through.

If the benefits of light gained were more than those of heat lost, I think that small windows on the north roof like those in the Six Pack would be beneficial, possibly with an insulated shutter. However, there are ways in which the north wall area can be utilized for purposes other than growing plants. For example, the workbench in the Ark is in a prime growing area, although it may be less convenient on the back wall, it would free up that area for plants.

Other ways of utilizing the back wall are water storage, sprout growing, the raising of earthworms or rabbits, or for herbs and varieties of ornamentals that do well in conditions of lower light.

Sardo:

A. It's empty! The Ark has approximately 1750 square feet of floor space. About 575 sq. ft. are used for agriculture and 400 for aquaculture. The remaining 775 is used for walkways, not including the suspended observation area. In addition, we are currently using only about ⅕ of the Ark's volume (17,000 ft^3).

B. I would use vertical space more efficiently—terrace the hell out of it—and make all walkways multifunctional, serving as thermal mass, retaining walls, and walkways at the same time.

Joe:

A. The air flow through the rock thermal storage bin and out through the ducts is far too constricted, and as a result, the energy requirements to move air are excessive. Some mechanically assisted air movement is desirable to turn air over, but good, open design of a rock storage could allow the same function at only ten to twenty percent of the present energy cost.

B. The problem is built in. In a different building, I would create spacious plenums for air flow and space for a low-speed, large-diameter fan—perhaps six-feet diameter for an Ark-sized building.

John W.:

A. The electric power requirement (a kilowatt for air pump and rock bin fan; another intermittent 2kw for pond resistance heaters in fish breeding tanks at least this winter) is much too high.

B. See redesign notes previous section . . . John Wolfe.

Ron:

A. The design is much too complex to be approachable by anyone short of a gifted artisan. The building is good for N.A.I., because it demonstrates how exciting solar architecture can be. This is both a positive and a negative attribute. The design does provide some interesting design success stories, e.g., structure wires.

B. I would use a more comprehensible, and simple, design. It would have to be one that would be adaptable as a whole or in part for different size bioshelters. Readily available and easily assembled materials should be used.

C. What Other Mistakes Were Made?
D. How Would You Fix Them?

Colleen:

C. Now, I do not know too much about architecture but, . . . if we could keep the same important angles of the building but lower the ceiling, I think we would have a tighter bioshelter.

In the agri-area, the third level is a dead pocket with less light, less air movement and quicker erosion than other levels. No go.

No wooden walkways. These are easy spots for rodents, slugs, and sow and pill bugs to hide during daylight.

The growing area is divided into many sections. A lot of this space becomes pathways. More feet tromping around means higher fatality for young plant life. I can't get into "Keep off the plant" signs. The division of plots also makes watering much more cumbersome.

The east end of building was never sufficiently insulated.

D. I would sink the bioshelter a third into the ground, or somehow decrease the height of building.

I would have two levels in the growing area. Each level would have one or at the most two central plots.

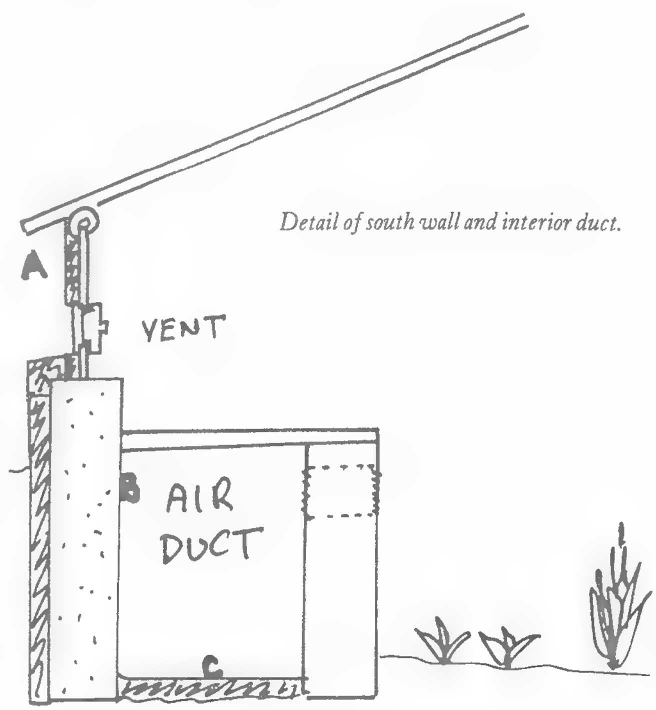
I would prefer earth, gravel or cement walkways.

Earle:

C. and *D.* The ventilation by convection in summer is too slow to cool the building. I would design for ventilation by convection. The best solution is Six Pack type low south vents, but these are not possible in this case. The next best solution would be screened vents opening inward on the west end walls, and on both east end walls.

The entrance thresholds are at ground level,so ice and snow block the doors in the winter. But it's too late to change the entrances.

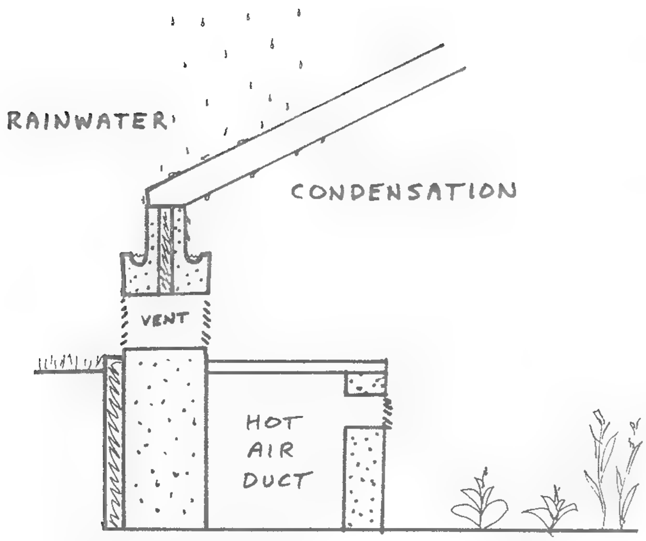
The south wall is inadequately insulated. Insulation should be placed; (a) outside, on the exterior of the plywood; (b) inside, between the air duct and the south foundation wall; and (c) on the floor of the duct (using loose vemiculite?).



Detail of south wall and interior duct.

The forced ventilation from the rock box is misdirected and misproportioned. We could cut new vents in the east side of the rock box to shoot air over the upper terraces.

There is wood at places where condensation collects, which will rot. We could cast special south foundation shapes to collect both rain and condensation water (see the following sketch).



Improved south wall design.

David B.:

C. and ***D.*** Electrical consumption is higher than necessary to operate the air circulation system in the greenhouse. An axial fan should be substituted for the centrifugal fan now used to store heat in the rocks and supply heat to the greenhouse. Axial fans have a better ratio of horsepower to CFM for low pressure drops than centrifugal fans. Electrical consumption would be lowered significantly.

The natural venting system is not of sufficient size to remove excess heat effectively in the summer. The lower vents of the greenhouse should approximate the surface area of the upper vent.

Infiltration in the winter is higher than necessary. The exterior openings should be weatherstripped.

Humidity levels could be reduced; an air-to-air heat exchange system would expel humidity and capture 80% of the exhausted reusable heat.

Al:

C. The noise in the building does not match the visual effect. The sound of motors and fans overrides the natural sounds.

D. Place all motors and fans in more soundproof enclosures, and produce neutral sounds like water to override the background. A lead or ceramic frog or flower in the concrete pond spitting water in the air, or anything that makes bubbling water sounds with low energy costs would do it.

David E.:

C. The other exterior areas will not weather well, particularly the areas between the Kalwall on the south solar roof. The triangular peak wood areas are warped and severely weathered.

D. Again, choice of wood and craftsmanship of fit are would-be preservation methods.

Ole:

C. and ***D.*** There is no airlock winter entry. Build one on the north side.

Jeff:

C. We should attempt, even if in peripheral ways, to have the bioshelter and its concept appeal ("strike home" maybe) to as wide a variety of people as possible.

D. I'm thinking mainly of incorporating the growing of flowers and houseplants into the existing agriculture program. Again I feel that these would be a major aesthetic plus on their own. Although a lot of people find it easier to identify with these than chard, but once the door is open, I believe they will get as much, if not more, fulfillment from raising edible plants (and all that entails) as well. Conceptually, the same holds true for aquaculture and the tropical fish hobbyist, though the logistics in integrating the two appear to be more difficult.

Sardo:

C. and ***D.*** The curved southern glazing has more surface area than a flat glazing, increasing heat loss and material costs. It is also a much more difficult and thus expensive design to fabricate. A flat southern glazing is more energy efficient, cheaper, and easier to construct. Also, the curved southern glazing sections are extremely difficult to repair or replace. I would try flat glazing sections with easily removable fastenings.

The southern kneewall is not high enough. Snow backs up the Kalwall panels quickly as it accumulates at the bottom of each section. I would raise the kneewall to 5′, to collect all the snowfall that slides off the glazing.

No thought was given to the drainage of interior condensation water. We could put a water barrier across the bottom of the glazing, which would empty water into a common gutter that gravity feeds into a pond (similar to our present operation, but a cleaner set-up).

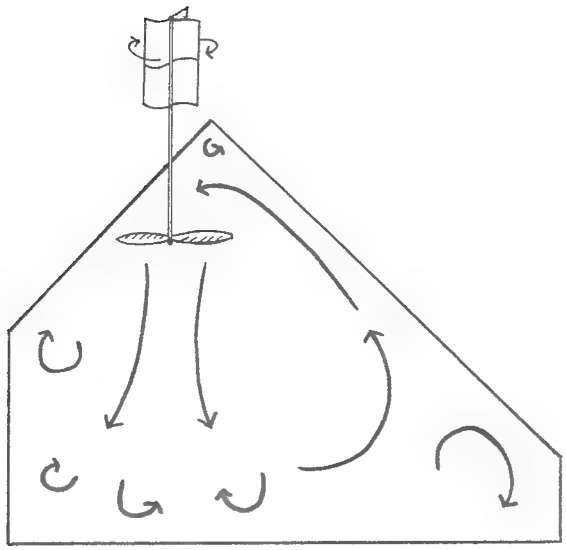
The suspended observation area heavily shades the growing area underneath it. If a suspended "observation-seedling-propagation" area is to be included in the design, the space underneath it should be used for work space or equipment (potting, fans, the computer, etc.).

A lot of warm air is lost through the doors being frequently opened. We should add a vestibule to the winter access door.

The inner glazing could have better light transmitting characteristics. We could use lighter and more transmittant multiple inner glazings.

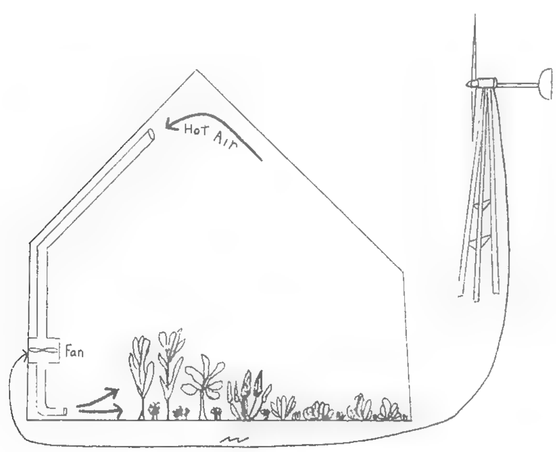
The south kneewall ventilators are not large enough. We could add several outward swinging ventilator doors in the kneewall, using the sane mechanism as we have on the roof ventilator.

Circulation of the air could be used to turn large



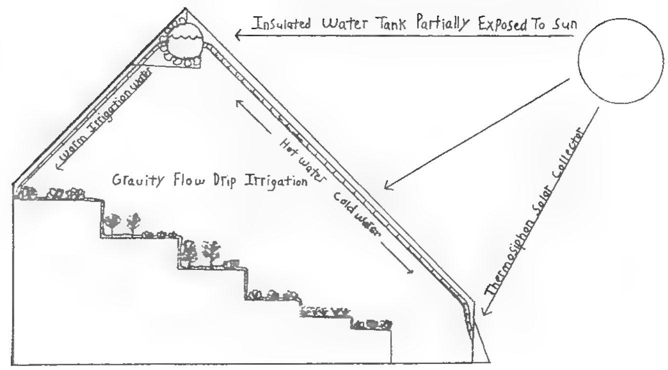
ceiling fans to force warmed air back down to soil level (see above sketch).

We should have large amounts of thermal mass close to the bottom of the building, to allow heat collected during the day to rise by convection to the growing areas above at night. Or we could use wind-powered recirculating fans (using electricity stored in 12 volt batteries, like those in cars) to bring warmed air from the ceiling back down to the growing area during the night.



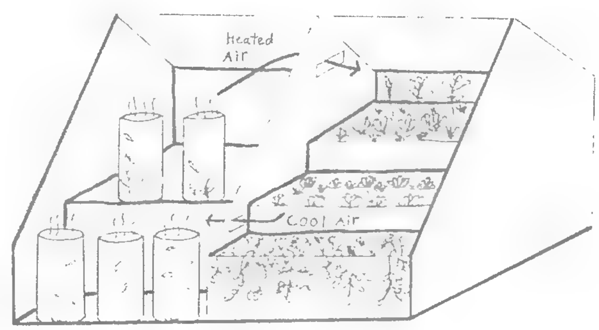
Propagation boxes shouldn't be heated electrically even for short periods. I would like to put these boxes on top of the compost box for heat and CO_2, or in the warmest part of the building, such as the suspended observation area. Right now they are in the coldest part of the Ark.

The water used in the Ark is too cold in the winter; any water used for irrigation should be preheated by the sun to warm the soil and avoid shocking the plants.



We could use thermal siphon solar collectors tied into a gravity fed water distribution and storage system.

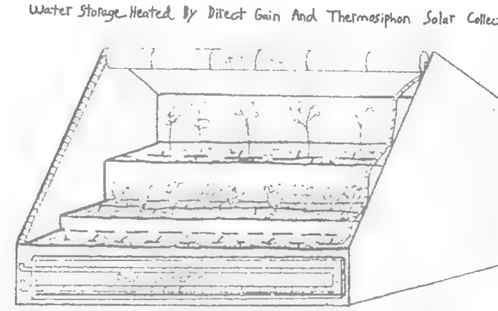
The agricultural and aquacultural areas should be separated by a partition, to let temperatures in the aqua section rise above levels which would be harmful to plants in the agri section. We could design high and low vents into the partition, which would be closed during the day and open at night to let air from the aqua section be carried by convection into the agriculture area.



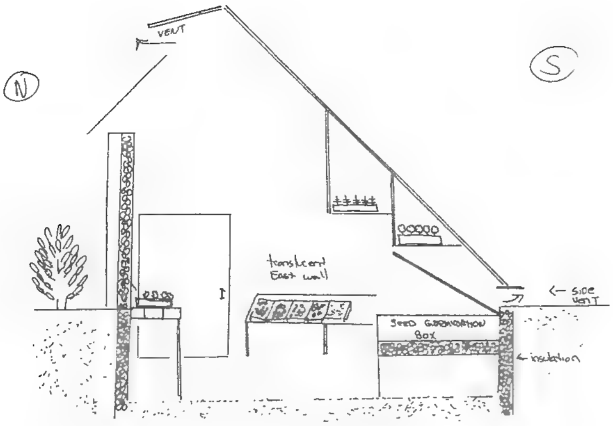
The small east-end door is not wide enough to let a wheelbarrow pass through—I'd like to widen the door to accommodate one. To have to open both doors results in lots of heat loss in the winter.

Irrigating crops with a hose takes too long. I would prefer a gravity fed drip irrigation system.

Water Storage Heated By Direct Gain And Thermosiphon Solar Collector



Solar Heated Water Gravity Fed To Plants Via Drip Irrigation System



Joe:

C. I am suspicious that we have condensation problems in the north wall insulation.

D. If the problem exists, I would create screened vent holes with a gutter-like fixture above them to keep out rain.

Ron:

C. and *D.* All sills should rapidly drain condensation to prevent growth of mold and algae. The lower panels at base of fiberglass should be insulated. More vents should have been included in the design.

The work space around the solar-algae ponds should be enlarged to make tending easier. The research platform shades too much. I would relocate it on the rock box. The rock storage box needs insulation on the bottom—maybe not, considering temperature of the earth and its contribution of insulation.

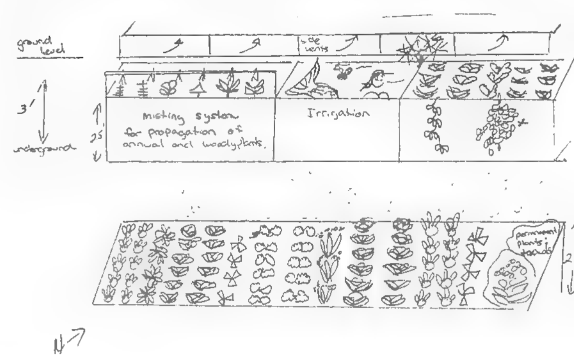
The irrigation pool should have been put at higher level, to allow for siphoning instead of pumping it. We should have included air-lock arrangement to prevent excessive winter air exchange; possibly revolving door, but this is perhaps too expensive.

Since the building is a demonstration we could use more glass windows. This would allow the public visual access of the building even when it is locked. An internal source of water is needed, either from a well or from town lines. Finally, the south footings should be deeper, to keep heat escaping underneath the building.

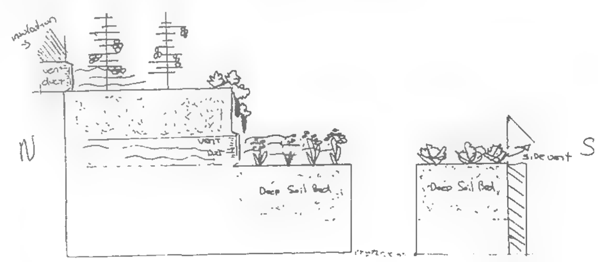
E. If You Were Rebuilding or Redesigning the Ark, How Would You Do It?

Colleen:

If I were redesigning the Ark, I would drop one-third of it down into the ground. The earth is a good and cheap organic insulator. I would combine the working area, the seed germination box and the transplant seedling area at the east end of the building into one anteroom. There would be a tight-knit mesh screen dividing this area from the rest of building. The rationale behind this "nursery" is primarily protection. If the general pest population could be deterred from getting to the youngsters, they would have a much better start in the Ark world. In the anteroom, I would build a step-type set of benches parallel to the south roof to get the maximum out of some of the space. The racks on the north wall would be for various pots and built-in bins for soil mixes would lie underneath the workbench. A sink with running water would help both the aqua and agri people.

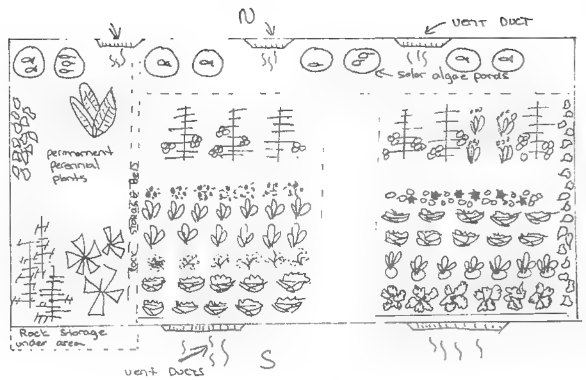


Opening the screen door into the Ark, the growing area would have two levels. On the ground level, a gravel footpath would cut across to west end. Going east to west on the lefthand side, first, there would be a raised propagation bed with an automatic mist system. In the center, a sunken fish pond with a charming mermaid and beside it, a raised bed. Adequate side vents would line the entire south side.



This section would be two-and-a-half feet in height and, compared to the outdoors, would be underground by half a foot. Across it would lie one long bed also raised two-and-a-half feet from pathway. If there were a rock storage area (and I would have one because I can see now that it's important, where before I was skeptical), this bed would run up to it. Along the rock storage wall, permanent, dwarf trees could disguise the wall and create a relatively undisturbed warm zone. A path would lead to the second level.

This section, about two feet higher, combines many old ideas. The back wall would be lined with solar-



algae ponds spaced for vents to blow air in between. The vents would be low to the ground and the air would come off the rock storage bed. There would be similar vents in the south wall of this level to circulate the air over the ground level.

To build into a hillside would be convenient. If the second level and the rock storage were the same height, one could extend the growing section and solar-algae ponds over rock storage. This would be a great permanent tropical forest area. A vine arborway would lead to the aqua kingdom. The second level growing area would consist of two central beds.

Earle:

I would arrange the aquaculture tanks in the highest position with a gravity flow water cycle from rain → storage → aquaculture → hydroponics → irrigation→out.

David B.:

With the above changes the Ark is a sensible and aesthetic approach to greenhouse architecture. Floor plans and areas might be changed to accommodate different growing areas.

The Cape Cod Ark successfully fulfilled the program requirements which were weighed by both the growing (agri/aqua) requirements and the "new architecture" approach.

Al:

We should possibly replace the rock storage with surface exposure storage and use overhead (slow turning) fans to mix the air. We could use more transparent glazing but I'd otherwise stick to the same type of design; but improve vertical space utilization.

David E.:

The shape and general structure are excellent. There are several areas I would focus on, to ease labor, and insure greater longetivity to the structure and support system. On the uppermost level, I would like to see a meditation area with mildew resistant cushions; we could also have a glass section directly in front of the desk for outside visual contact (these changes would require a slight enlargement of the uppermost level).

With regard to the electrical components (relative to research versus personal use and lifestyle),we need more grounded receptacles near solar tanks for heaters, etc. (if used extensively). There is a real danger with heaters now, since they are not grounded and moisture near the tanks is high. The aquaculture staff is aware of this, and is careful. Light fixtures hang from wiring, and there is rust appearing near the junction with the electrical boxes. We need a covering of permanent pipe with good seals here. My personal option for the Ark's electrical system would be 24 volt DC wind limited power.

My first preference for heat is like the P.E.I. design—limited contact with the living area. Auxiliary heat would be wood fuel for a "sauna" room, with vents to the Ark to maintain the winter fish stock, as necessary.

We need further emphasis upon a permanent drainage system for the solar-algae ponds (always necessary to some degree for detritus removal), which is integrated into a good irrigation system for the agricultural areas.

Ole:

I would consider Tedlar or teflon for higher levels of light and energy. I think an additional 10% could be obtained.

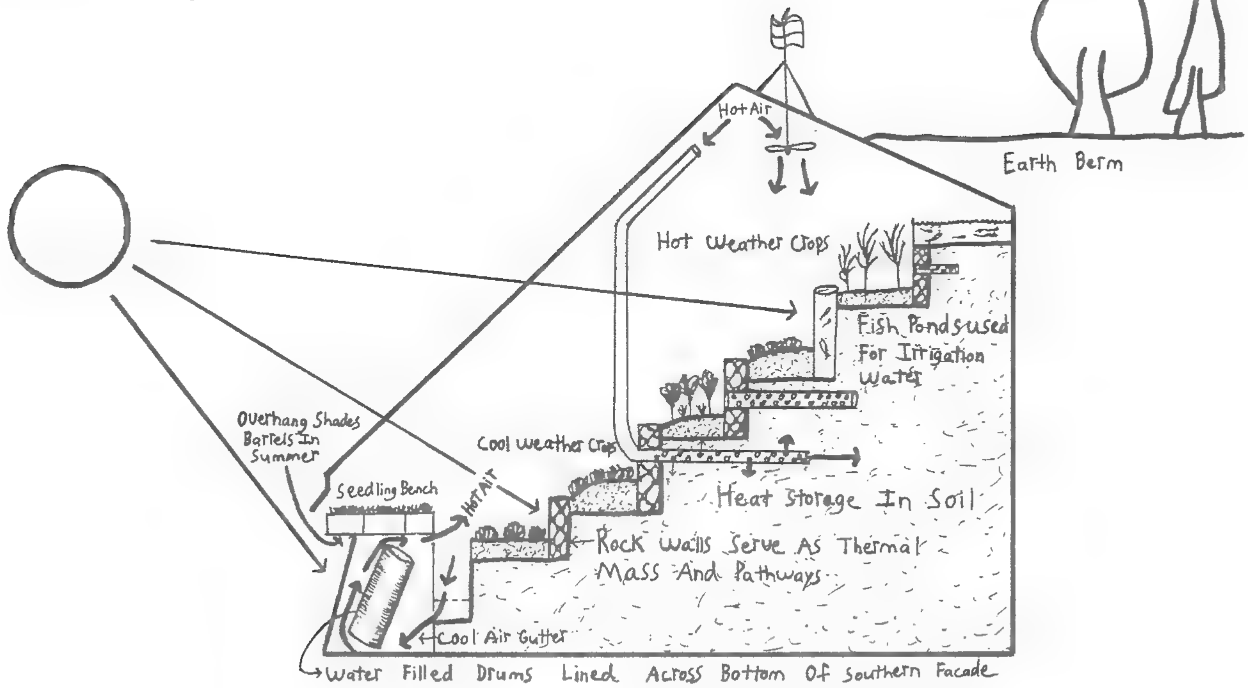
Jeff:

I really haven't considered this question in many of its exhilarating and complex details. Basically though, I would make it the hub, as it were, of my home. The only access between "rooms" would be via the greenhouse portion and many of the "rooms" would be virtually indistinguishable from it; the place for eating and a studio of sorts are two that come to mind immediately as well as a sauna and bathroom nestled in groves of bamboo in containers.

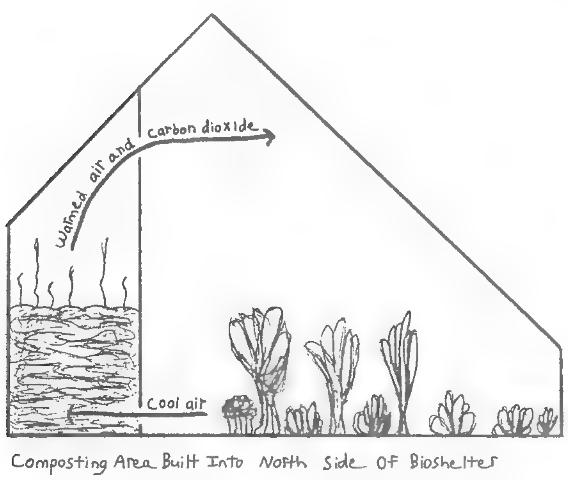
Photo by Hilde Maingay

Sardo:

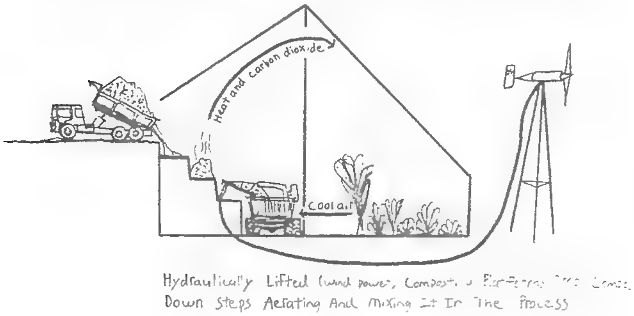
Sardo Ark. Fantasy # 1



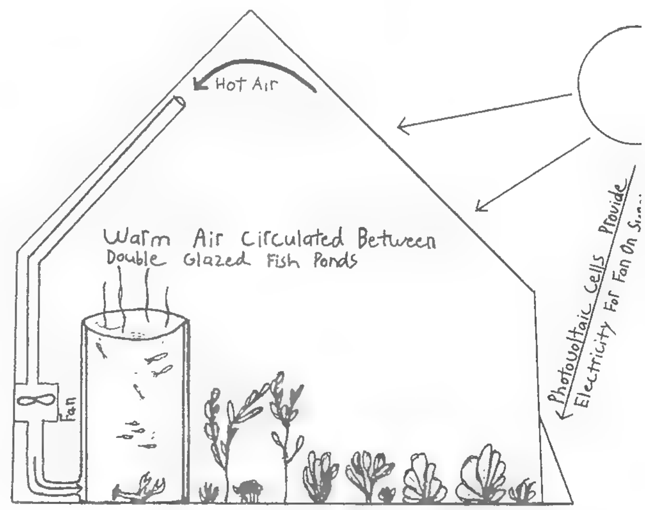
Sardo Ark Fantasy # 2: Composting Bioshelter



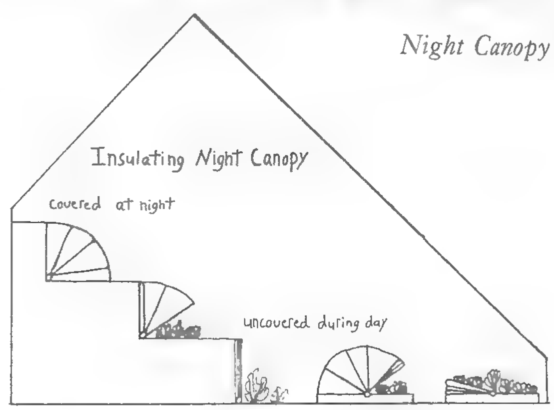
Sardo Ark Fantasy # 3: Community Composting Bioshelter



Sardo Ark Fantasy # 4: Solar Cell Powered Ark



Night Canopy Ark



Joe:

I would retain the basic design—it is sound. But I would investigate the feasibility of eliminating the rock thermal storage function entirely in favor of increased thermal contact with water and soil. To accomplish this would require low-speed, low-wattage blade fans to maintain air movement, replacing that function of the rock storage blower. More water mass could be needed, closer to the proportions of water mass to glazing area of the P.E.I. Ark. A greater number of smaller solar-algae ponds would provide a better surface area/volume ratio for passive heat exchange. I like John Wolfe's suggestion of raised beds both for the benefit of workers and for soil-to-air thermal contact over a much greater area.

John W.:

I would avoid the rock storage and big fan and store more heat in the soil. Raised beds with masonry side walls could reduce back strain and increase the effective thermal mass of the soil. Masonry ducts (of concrete blocks or ceramic pipes) through the soil would also increase surface area and heat exchange.

I would reduce the power needed for aeration. We now use 25 watts of power per pond. We could use 3 watts for almost the same amount of air. The problem is frictional loss in the long, sharply bent compressed air lines; 3 watt Metaframe aquarium pumps for 24 ponds (used 12 hours each day) have a low enough power requirement for wind electricity.

I would augment CO_2 and heat with large-scale composting: low plant yields and low temperatures this year (despite warm cloudy weather) may be partially due to having no compost pile. If Sardo's calculations are correct, the moderate 4′ x 4′ x 4′ pile last year produced enormous amounts of heat and CO_2.

I think we should avoid thermal circuits. Shallow foundation walls, such as the south edge of the Ark, can't be insulated deep enough to avoid a short path through the ground to the outside air for escaping heat. Dig deeper! Use a thinner, more transparent inner layer of Kalwall (.025″ rather than .04″). Make the glazing flat rather than troughed, to reduce surface area, and thus heat losses (by 12% through the face!). Increase light transmittance by presenting a less oblique plane to direct solar radiation. Triple glaze with a third, middle solar film (very high in light transmission characteristics), or with a movable insulating night curtain.

We should get resistance heaters out of the seedling beds. We could put the seedling box on the compost for warmth, *or* put the box above a tank of hot antifreeze, attached to a thermosiphoning liquid collector (using Sean Buckley's simple "thermic diode" oil valve to avoid back siphoning at night). *Or* we could insulate the heck out of the box (e.g. use a clamp-locking board insulation top, rather than the flimsy Kalwall cover) and drive resistance heaters with (very little) wind electricity.

Ron:

I'd first buy a case of beer—better make that two cases. Then I'd get together a solar engineer, an architect, a builder, a greenhouse agriculturist, an aquaculturist (closed-system type), an interested backyard gardener, a couple of people who've had experience in such a structure (these could be some of those already listed), and a visionary with good economic perspective to round things out. I'd then take the child-in-a-candy-store approach and make the first task to have each of them describe what the ideal design would be to accommodate their particular interest, each also putting in their own aesthetic preferences. The real work would begin in the synthesis of this kind of structure. We would evaluate designs that had been considered or built previously. After this first session a series would follow with everyone working independently between them to bring up possibilities not initially considered. This would take more time and a lot more beer.

I guess the underlying basis for the design would be to make the building as passive as possible in terms of energy use.

Also, the outdoor courtyards would have to be assessed for their economic viability. Concrete lasts a long time, but it may be too expensive.

F. Miscellaneous Comments Related to Prior Criticisms and Changes

Colleen:

Music (live or otherwise) would be appreciated by all. The mermaid would curse you if the Ark were not kept clean. If anyone smoked a cigarette or such, he or she would be transformed into a toad. On the serious side, the building would have to be better insulated than the existing Ark, on all four sides. If the tech were ready with an insulated type glass, I would consider the outside roof sheet of such material, and the inside fiberglass. A night shade, maybe.

Denise:

On occasion I am aware of the large, unoccupied air spaces in the Ark. If it were to be used for community gardening, more of its space would be needed for growing—multi-levels or glass shelves or increased terracing or hanging gardens?

Earle:

The electric immersion heaters in the aquaculture breeding tanks must be recognized as a significant fossil fuel input to the functioning of the building, and

an indication of an inappropriate choice of fish or an ineffective solar design, and a tendency toward high-energy aeration, heating, etc., which is frowned upon.

The estimated lifetime of the structure before major problems is still short in any long-term conserver society scenario.

David B.:

As a postscript to E. In designing the Ark, we endeavored to do more than create an environment. We tried to develop a greenhouse vernacular—say a visual statement—something that wouldn't wear off quickly. I wouldn't rebuild or redesign the Ark as an object, but rather reorganize the concepts into a new form. Let's face it, we've learned lots of new stuff since then.

Al:

Before expanding or doing again, the problem of door sealing and wood exposure should be given some attention.

Ole:

Light levels should be compared with levels in *regular* greenhouses in the area. What is the premium paid in terms of loss of light?

Conn:

Its beauty is its central value. Keep things beautiful!

Jeff:

I feel that the use of microprocessors to disseminate information and mediate between the processes of the ecosystem and its human nurturer(s) is antithetic to the ultimate benefit to humanity which might be derived from bioshelter. How is a person to begin to revere and understand life—one's own, others, and nature—when communication with their natural life support (enhancement at any rate) processes is performed vicariously and mechanically. I'm convinced that the use of microprocessors to enhance the "market appeal" of bioshelter will result in superficial victory (positive and resulting from misconceived means) at best, a Faustian pact at worst.

Sardo:

Our management of the Ark as a solar-heated structure needs improvement. A seasonal management scheme needs to be established for crop selection, ventilation, fan duration and whatever. I realize this is evolving slowly. We need to learn how to exploit fully the temperature extremes in the Ark over the year instead of fighting them by ventilating or adding heaters to fish tanks. For example, large thermal reservoirs (water, stone, etc.) could be designed into, under, or near future bioshelters to absorb the summer's heat for slow release over the winter.

Joe:

I have considered other bioshelter shapes, in particular the geodesic dome, A potential advantage of a dome would be high volume at low cost and a shape that promotes natural convection. However, the ratio of solar aperture to heat-losing glazing area would be poorer even if part of the dome cover is opaque insulation with high thermal resistance. Reduction of this ratio would lower average winter temperatures unless scale is made so large as to permit seasonal heat storage, which would require a deep internal water body, regardless of dome area. It seems that great volume for plants is of limited value, as solar aperture and the resulting insulation is the growth-limiting factor. I would pay the moderate energy cost of mechanically driven air movement and stick with the elongated east-west building shape.

John W.:

Consider . . . Ark as huge crop dryer in autumn to build up heat stores and dry out fungus and mildew that normally attack wood.

Ron:

At this time, I would suggest that a meeting be conducted with all those interested to try and put together the changes that the Cape Cod Ark needs now. Those most significant should be implemented as soon as possible. I think the building has been an excellent start toward this kind of architectural design—an excellent learning tool.

Section 2

A. How Did The Ark Open Your Sense of Future Possibilities?

Colleen:

Basically, the Ark has broadened my future by creating an environment where food and ornamental crops can be grown successfully without chemical pesticides and fungicides. Even though food has been grown for hundreds, thousands of years without the chemical agents, in my own lifetime, insecticides have been used as a crutch for maximum productivity. As a grower, abuse of chemicals drove me away from greenhouses. Not only has the Ark allowed me to return to a practice that I thoroughly enjoy, but it provides an atmosphere to develop and experiment various techniques in controlling insect pests. The Ark is a challenge. Over two years, I have seen progress and setbacks. There are many unexplained phenomena. There are endless possibilities as to where the Ark can be applied.

Denise:

It is a rallying cry for passive solar with attendant possibilities of creative uses for that heat.

David B.:

N.A.I. and Solsearch have been a successful relationship because of freedoms we enjoyed in developing the conceptual and architectural work of creating Arks. The most outstanding feature about the Arks has been their unprecedented success as heat capturing and trapping structures which has led us all to believe that these concepts can be expanded into both the production and residential fields.

Al:

As a nonverbal statement that says it can be done—to use the sun as a heat sourse without high technology or plumbers' nightmares.

David E.:

I now contemplate no personal or group living structure without a similar ark structure physically connected to or associated with it.

Ole:

Limitation on money and energy proved not to be limits but rather to offer new and exciting possibilities.

Tanis:

The introduction of new materials and the new sense of space in that context has opened a window for me both visually and practically.

Conn:

By offering hope to northern climes. Helps elude nasty choice of going nuclear so as to sustain cold civilizations, or going primitive and dispersing inhabitants (or killing them off).

Jeff:

It has opened up some of my ideas of future possibilities by manifesting them into reality. It offers an alluring and pragmatic vehicle through which people can come into closer contact with life's basic processes. A time when people's lives are balanced out with a deep-felt reverence and responsibility towards nature in whatever form now seems a great leap closer.

Sardo:

Immensely! It's one thing to talk about a solar-heated building and another thing to experience the daily and seasonal cycles and rhythms within one. I now know, without a doubt, that the sun can supply a major portion of our energy needs safely and cleanly if people would only let it. The latest solar forecasts predict the sun could supply 25% of our heating needs by the year 2000. Why wait until the year 2000???? We already have the knowledge, skills and material needed for a major transition toward a solar-oriented society. I believe this percentage could be much greater if people were turned onto the realities of using solar energy. The Ark has "blown away" every winter visitor I've seen walk in. The hidden beauty and warmth trapped within the Ark's translucent glazings have converted one hell of a lot of people into solar advocates. Let's hear it for educating the masses! As H. G. Wells said, "Human history more and more becomes a race between education and catastrophe."

Joe:

It has demonstrated to me the technical feasibility of year-round local food production in temperate climates with potentially vast energy savings and desirable decentralization. I am discouraged that institutional and social inertia may slow the spread of such appropriate technology to the degree that its widespread use will be foreclosed by institutionalized hard technology and/or economic collapse.

John T.:

Some of the things going on in the Ark are literally extraordinary. The agricultural ecosystem is behaving like a coherent, integrated whole that has responded creatively to our initial design—including not using poisons and the "seeding" of a wide diversity of organisms from very different kinds of "parent" ecosystems—and to the care and affection lavished on it by its tenders.

It's as if by doing all the above we have increased its genetic possibilities and its ecological strategies to the point where it has created an ecosystem highly adapted to the unique environment that is the Ark.

I hoped this would happen, but I didn't dare believe it. The results fly in the face of conventional wisdom which says greenhouse environments are hot beds for disease and pestilence. Normally, this is true. In our case, organisms, which are our agricultural allies, have invaded the Ark on their own, or have been brought in as passengers by seeding it with diverse soils. Other allies, like the anti-whitefly wasp, *Encarsia*, have been consciously introduced together, and over time they have enabled the Ark's ecosystem to develop a healthy balance and to keep pests and disease at bay. Somehow it has been given enough biological information to evolve ecologically to this exceptional state.

I am aware of the meaning of all this. It opens a tiny portal to a new kind of agriculture that borrows widely from the planet for its ecological integrity, an agriculture with internal patterns akin to those of the forest, but with dynamic components uniquely its own.

John W.:

By showing the enormous benefits from a living, breathing and *im*perfect solar design. The next generation of bioshelters will be stupendous! This one has honed our understanding to a keen edge.

Ron:

By working in and around the building, my understanding of climate, ecology, food production, architecture, and their integration has been broadened and deepened. It has been a stepping stone toward the design of how an ecological, renewable resource based society may be formed. This is true of all N.A.I. bioshelters.

B. How Has the Ark Affected Your Work and Career?

Colleen:

That's a tough one to say because I can never predict my own future. I am really one of those day-to-day people. However . . . without even hearing about N.A.I., I might have followed two courses. The first would have been return to school and become some kind of professional. Whether or not I would have found a direction into integrated pest management is questionable. My humanistic tendencies may have thrown me into a service job. Or secondly, I might have leaned toward a horticultural therapy field, applying these techniques in various rehabilitation modes for institutional people re-entering into community life. If I had been desperate, I would have gone into a horticultural business. Finally, and this will truly come in the future, I will farm. The Ark has allowed me to bypass many things I really did not want to do and to put my foot in the right direction—not to mention the fact that it constantly makes me think.

Denise:

It has certainly focused my family's attention on plants, solar, conservation; it has expanded our awareness of the lovely green possibilities in a black-topped world. Here, it "restoreth my soul"—to go from inside the house to inside the Ark is a constant pleasure. Taj Mahal of Cape Cod.

David B:

The concepts developed in the Ark can be applied to other architectural forms. It has been our effort to package these ideas into projects as a new philosophical approach to a new architecture.

Al:

Most people have goals to "get to the country" whether as a weekend retreat for a corporate executive or as a vacation for a young couple. Our kind seems to be part of a balanced triangle, with flora and fauna being the other elements. Any imbalance seems to drive for compensation as in the first statement above. By bringing these elements together in a working environment which has some adaptability to modern living situations, a more harmonious life can be obtained.

David E.:

It has emphasized the need to collect pertinent information such that I personally understand is the construction, design and implementation of such a structure.

Ole:

The Cape Cod Ark proved that bioshelters can have their own strong form of language.

Tanis:

The Ark hasn't had a concrete effect on me yet—I am still absorbing that. The light is quite different to my visual sense.

Sardo:

Over the past year, I have been able to explore many diverse and interdependent biological and physical components inside the Ark. The Ark has been an incredible classroom for me and for all of the students I have worked with. Thanks to many inspiring moments in the Ark I plan to continue integrating biology, engineering and education in my formal studies and career over the coming years.

Joe:

Only indirectly.

John W.:

C'mon, you're kidding? It's given this tender, recent college graduate both work and a strengthened direction.

Specifically, it's let me combine ecology and engineering. Now that they've fused, I'm not going to let them separate in my work.

Ron:

Hey! it gave me a job! This aside, it also opened me to working and thinking toward the understanding of how an existence would be woven into a symbiosis with the environment. Being in the building on a cold winter day stimulates the imagination and frees one from thinking of a temperate climate as a restrictive, expensive one in which to exist during the colder times of the year.

C. Has It Been a Creative Integrative Statement, as a Bioshelter?

Colleen:

No question about it. Yes. In many ways the Ark is both integrative and creative, simply in combining aquaculture and agriculture under the same roof and seeing them work together. The Ark changes every

week with new apparatus, different modes of management, and different populations of countless living organisms. The most outstanding is in the word bioshelter itself. A structure with an ongoing community of life.

Denise:
Oh my yes.

Earle:
Not a bad first shot, but the water cycle, water heat-storage distribution and air circulation are still fragmented.

David B.:
The Ark as an architectural solution is certainly an integration of form and function. Its subtlety of structure and internal systems based on laws of thermal dynamics produced within severe limitations of simple technologies and limited economics, suggest the importance of the bioshelter as an important alternative to present food-producing models.

Al:
Yes.

David E.:
To a limited degree, since no one lives in the Ark or feels a 24-hour "living" association with the dynamics of the biological systems. Another limitation—wind power is not yet integrated (understandably).

Ole:
Yes. Cost, structure, and function are all integrated into an aesthetically exciting environment.

Tanis:
I would like to see more play with space both grounded and suspended, with either materials or growing things.

Conn:
Yep. What it now needs is *context*. Perhaps via village design.

Jeff:
It has been a creative integrative statement period! Bravo!

Sardo:
Absolutely! It's funky, alive, beautiful and by golly, it works! What more can you ask? Of course, some mistakes were made as would be expected. The only way to realize these is by doing it though. As E. F. Schumacher said, "We are always having all sorts of clever ideas about optimizing something before it even exists. I think the stupid 'man' who says 'something is better than nothing' is much more intelligent than the clever chap who will not touch anything unless it is optimal."

Joe:
Yes.

John W.:
Yes, amazingly so. Ecologists like Robert May now maintain that species diversity indicates environmental stability. The rich flora and fauna diversity in the Ark (species from both temperate and tropical regions) demonstrates a stable, inviting climate.

Ron:
Yes. As I stated before, it has been a very good introduction into possibilities of solar architecture with integrated food-producing components within its design.

D. What Kinds of Future Work Would You Like to See?

Colleen:
Now this is going to be strictly biased. I would like to see a rigorous program developed to evaluate the economics of food production inside the Ark. This would include accounting for space, time, fertilization, pest control, waste and production of the most popular and marketable vegetables. I would like to see a progression of biological agents, mostly insects, introduced into the Ark and an observation of their establishment or extinction. If this did happen successfully, what would be the order of these new insects? I would also like to see some development of vegetable varieties that acclimatized to Ark-type buildings for future production.

Denise:
More sampling for possible accumulation of contaminants. More pest control management; more cash crop experiments. Is the ratio of solar-algae ponds to Ark space already determined? Energetics of composting, solar energetics: how is the glazing holding up? Is condensation leaching anything out? Wind hook-up for aeration.

Earle:
I would like to see a heat budget analysis of building, wind-chill and windbreak effects; gray water treatment; greater use of perennials; vegetables chosen for nutrition rather than profit; polyculture aquaculture run on a constant rather than seasonal batch; internal water supply and storage; walk-in root storage in the earth berm.

Al:

How about including animals in the Ark "system"? I know this is not readily possible, at N.A.I., but even a loose link would be preferable.

David E.:

See section 1.E.

Conn:

I'd like two *disciplined* projects: One, to test food-growing capability for X number of adults (and no one else). Two, to test non-food crops (e.g. tree seedlings).

Jeff:

See Section 1, B. and D.

Sardo:

We should study: CO_2 dynamics, seasonal thermal storage, and night insulation over plant beds. Sprouts (test seeds which need soil to sprout) would be a high turnover crop!

Joe:

I would like to see comprehensive energetics and mass flow research to show where heat, air, and water travel through, into and out of the building over time. I would also like to see the continuation of integrated agriculture and aquaculture research that is going on currently.

Photo by John Todd

John W.:

I would like to study CO_2 dynamics (measure the stuff); the possibility of annual heat storage in soil beneath the Ark; using the Ark as a huge crop dryer in autumn. We could reintroduce tropical food plants; integrate solar ponds into a low-flow solar river, with hydroponics to strip out nitrogen compounds. I'd like to see more tree propagation work. I'd also like the economic analyses to be expanded. This will give us good baseline data for future design.

As is, there are a number of projects presently underway. With their conclusion, I think they will lead us to the next priorities to be researched.

Section 3: Optional.

A. Discuss Scale, Function and Social Use That Arks Might Be Developed For. Please Discuss the Ones That Personally Interest You.

Colleen:

I have a strong desire to develop the use of an Ark as an educational tool, a place where everyday people, not just new-age, or middle-class types, could learn simple, efficient techniques to grow food for their family in a bioshelter year round, something on the order of an intensive seminar.

Denise:

The community garden idea, or a community greenhouse (for houseplants, exotics, and shrubs on a commercial scale) most interest me. That scale would make it financially feasible . . . like arboreta or aviaries, it calls forth a loyalty and pride and delight in function that could attract a group dedicated to its growth and maintenance.
(A thought—The Ark as a research space is different from Ark as an agricultural (or whatever) space. We have a complicated system there due to fragility of fish that must be simplified to be widely accepted outside this Farm. Is it just the search for the Perfect Fish that will do it? How best reduce the criticalness of these cold spells?)

David B.:

Energy concepts developed in N.A.I. Arks have been picked up by other research groups and governments as approaches to food production. Unfortunately some of the philosophies of the bioshelter design get lost in these interpretations.

We've been seriously proposing "Granny Arks" as housing and horticulture centers as an alternative to "elderly housing."

These systems are easily translated into urban solutions for housing and growing.

David E.:

Individual arks offer biodiversity, and food for a family or a small group. Community arks could be for specific crops, or groups of crops with an environmental control bias.

The functions of individual or community arks could be research (if appropriate) into psychophysiological interplay, towards understanding the rhythms of success or failure in growth systems; teaching; and lifestyle at any level, a constant interplay of individuals with the biological process of the ark.

Social possibilities include music, small group meditation, and other activities which harmonize with a greenhouse atmosphere. Social function is limited by economics to some degree, which necessitates that its primary use be growing food. More appropriate uses might be as a solar house, a solar-wood sauna or a large bathing hot tub.

Ole:

The Ark as a place to be is overwhelming to me and we keep trying to integrate the bioshelter environment into our houses. We are particularly interested in building a "Granny Ark," an old people's home—food production center.

Tanis:

What interests me personally is small Arks—there could be any number of uses—I see most as educational facilities. However, in my wildest dream I see myself running a large commercial venture composed of a few Arks. Their uses would reflect the real commercial needs of the community. Trade of information, materials, foods that were pertinent to the particular culture of that particular location. Solar shopping center!! Imagine! Appropriate Technology Bureau for each locale—and a cup of espresso!

Conn:

I'd like to see on-site experiments in *scale* of Arks, which would create, by necessity, experiments in functions. Examples: Arks as a nucleus for a 6-household cluster-zone development; Arks as neo-barns; Arks as discreet single-dwelling adjuncts.

Sardo:

I'd like to see an Ark on every block or in every neighborhood. Ideally, they could be cooperatively financed and managed. Each one might be the size of a small-to-medium-sized warehouse. They could supplement people's diets with tasty and nutritious plant and fish crops throughout the cooler months and provide vegetable and tree seedlings for outdoor planting. Equally important, they would offer a peaceful place to retreat to where one could experience many of the colors, smells, and sounds of summer in the dead of winter.

Here's a funky cooperative/capitalistic idea: I've been dreaming about opening up a bioshelter cafe for quite a while. It would be a great way to combine many of my own interests (growing food, designing shelter, cooking, turning people onto more ecological ways of living, etc.). What could be more elegant than seeing your dinner picked and prepared in front of your very eyes!

Joe:

Thermal performance of the building depends primarily on area-to-area ratios (e.g., glazing area versus heat-exchange surface area) and area to water volume ratios that become independent of overall building size if water is kept in particular size containers covering a particular fraction of the floor area. As a result, there is no substantial advantage here to very large size. The architectural cost-per-square-foot as a function of scale should be investigated. For commercial uses, the Ark may be too small for the current business paradigm, but that does not address the issue of household industry.

John W.:

The present scale of the Ark, about two thousand square feet, looks energetically and economically efficient. Many social arrangements to build and use this scale bioshelter can be imagined. These include use as a local food cooperative that could finance construction, hire a part-time tender, and sell the produce to co-op members; a group of families that could share costs, labor and yields; high quality restaurants that could join bioshelter and dining room: Patrons could watch (through a glass partition wall) their salad being picked or their fresh fish dinner being caught! People would come from miles around to eat at such a place.

Ron:

Arks can be used for education, to increase our awareness of alternative paths for survival. Arks can be used to put people, even in urban settings, in direct contact with the living world. This will give them a sense of what often is taken for granted for their own existences. It will also present them with a feeling of the responsibility they must take for the environment that supports them. It will show them how sensitive an ecosystem is. This should increase their awareness of the impact of human industrial enterprises upon the environment.

B. Do You Think a Design Like the Ark Can Help Revise and Rationalize Agriculture in the Northeast? If so, How?

David E.:

Economic agriculture? It cannot compete with many crops from farm machines, relative to wholesale price structure. We have the same problem with fish culture to some degree. Hence economics of "organic" or "good" food is a limited but realized market.

For home grown, "garden" oriented food supply, the Ark does help to revise by more growing time, and more personal food on small community or family level.

Relative to economics, certain unusual crops (black forest mushrooms) might eventually be harvested ($3.00 lb. wholesale) and be successful in competition with agribusiness.

Ole:

More production trials need to be done. We are currently working on a proposal for Sudbury, Ontario with an acre of solar greenhouses.

Conn:

For sure.

Essential is the establishment of *direct-marketing* schemes. Farmers' markets are doing gonzo business. With proper infrastructure, one could see a reliable year-round market for fresh, nontoxic produce.

A lone Ark tender, however, would have a hell of a hard time selling his/her stuff.

Jeff:

I certainly hope so!

Joe:

I feel that the impact on commercial scale agriculture for distribution to supermarkets will be the slowest, since that system is the most centralized. I see three quicker changes. One is at the household level, for solar add-on spaces for existing houses as well as solar design of new houses. From a thermal point of view, greenhouse add-ons in the northeast are about a break-even proposition especially with efficient night shutters. They also offer extra space to stretch and breathe good smells, be in the sun, and to work with soil in the winter as a recreation from the jobs most people have. For retailing of food, the farm-stand type of business seems best adapted for application of bioshelters. Another important area is in restaurants growing and providing fresher foods. Vegetarian restaurants are likely to take the lead in this area, since their clientele is more likely to appreciate the difference. In addition, vegetarian restaurant proprietors will be socially and psychologically more inclined to favor growing their own food.

John W.:

Arks could provide low-cost tree and vegetable seedlings to local farmers; dry crops such as apples in the fall; expand aquaculture, by overwintering fish fry and breeder-size adults that could be cultured in cages or shallow ponds in summer; provide off-season produce to local markets.

Ron:

I'm glad this question is optional. It reminds me of history questions I used to get on high school exams: "Compare and contrast the economics, and social and political systems of the first Ming Dynasty to present Chinese systems." (10 minutes).

I don't think we can really miss with the Ark-type design. The prices of fuel and food are skyrocketing. The most important criteria to consider are the cost of materials in construction and the lifetime and maintenance of these structures. I feel the Ark has demonstrated that solar-based designs will work. We just need to tighten up and eliminate some of the problems we've discovered and it should be a viable technology. Of all the problems that have been discussed over the last two years, I have yet to hear of one that someone within N.A.I. has not been able to resolve. January will always be January, but who knows—a little assistance from photovoltaics may eliminate our low light problems. Wind power auxiliaries incorporated in designs should help bring us to an even more integrated working system.

PART 4—EXPERIENCES WITH SOME OF THE ARK'S SUBCOMPONENTS

Solar Aquaculture Energetics and Its Contribution to the Ark Climate

John Wolfe

The 14 solar-algae ponds now inside the Ark act not only as fish culturing units, but also as passive solar collectors with internal heat storage. Daily wintertime temperature fluctuations in the ponds provide some indication of the amount of heat stored and later released. Amplitudes in temperature oscillations averaged at least 2½°C. this past winter. Since the ponds contain 2.3 to 2.5 cubic meters of water, this represents six million calories absorbed, stored and released by each pond over an average 24-hour period. This represents a total of 84 million calories daily contributed by the aquaculture facility. In four winters this heat will equal the amount of energy expended in manufacturing the pond (calculations are detailed in the Aquaculture section). Over the expected lifetime of the pond, five times as much useful energy will be generated than was spent in its creation.

Photo by John Todd

Condensation Cycles

Robert Sardinsky

A portion of the solar energy trapped in the Ark interacts with plants, soil and uncovered fish ponds to create a relatively humid environment. The resultant water vapor eventually either condenses inside the building or ex-filtrates to the outside. Large amounts of energy are transferred in these processes. During February and March of 1978, we measured the amount of water that condensed on the southern glazing. We were interested in both tracing the flow of water through the Ark's hydrologic cycle and in the heat losses from evaporation inside the building.

The 20 curved panels of fiberglass on the southern facade lend themselves to the ready collection of condensed water. Water condenses at night on the inner side of the two fiberglass skins and runs to the bottom of each column. To collect it we applied a bead of silicon caulk across each glazing a foot above the bottom end, but the caulk was difficult to work with and its rounded bead did not stop the flow of condensation water. Then we tried a ¼-inch band of closed-cell, adhesive-backed weather stripping which funneled all condensation water to the center of the glazing where it accumulated and dripped down into a collection pan. Previously, condensation water drained onto a wooden sill plate where eventually it would have caused rotting problems.

We measured condensation run-off from the 14 eastern panels. Approximately 3.5 pints of water was collected from each of the five eastern-most panels daily, one pint from the middle four, and 3.2 pints from the five westernmost panels. Variation in the microclimate inside the Ark can account for the differences in condensed water. The eastern end has the lowest temperatures because of the negligible thermal mass, large glazed area and the long distance from the rock storage ventilation system. When moisture-laden air enters this section its ability to hold water decreases with the lower temperatures and once the water vapor touches the glazing, less cooling has to occur for the water vapor to reach its dew point and condense. The westernmost panels stand above an open fish pond, which accounts for the large quantity of water collected there.

Tremendous amounts of energy are consumed and released in the evaporation process. During the day, evaporation can occur until the air becomes saturated. The saturation point depends on the air temperatures; the amount of water that can be held by air doubles with every 20°F. increase in temperature. The evaporation process absorbs heat at a rate of 600 calories per gram of water. Water vapor produced inside the Ark eventually either condenses on some cool object, such as the glazing, or is carried outside by escaping air. Most condensation on the glazing occurs during and shortly after sunset when air temperatures rapidly

drop, decreasing the amount of water the air can hold. The subsequent condensation of water on the inner glazings creates a heat transfer path to the conductive and radiative paths. Between five and fifteen gallons of water condense on the southern glazings each winter night. In the process, 4,500–13,000 Btu. stored in the water vapor are transferred to the glazings as the heat of vaporization (600 cal/g water) is released. This evaporative heat transfer increases thermal conduction to the inner glazing surface but does not affect the insulation value of the air space between the glazings. As a result, net thermal conduction is increased by condensation, but only slightly.

Composting and Carbon Dioxide Production

Robert Sardinsky

For many years we have been interested in the potential benefits of recycling organic wastes through composting. During the winter of 1977–78, we carried out an experimental composting program inside the Ark. We hoped to convert organic wastes into a nutrient-rich, soil-building product and to supply the Ark with additional heat and with atmospheric carbon dioxide (CO_2), by-products of microbial activities. We were curious about CO_2 contribution of the compost for plant fertilization as well as for supplementary heat for climate control. This paper describes our composting activities in the Ark and estimates the amounts of CO_2 and heat released.

We built a 4′ x 4′ x 4′ New Zealand compost box with scrap lumber. It had an elevated floor made of chicken wire to facilitate aeration. There was a wooden channel on two of the corner posts to allow the front wall boards to be slid in and out, and provide easy access for loading and unloading. We placed the compost box in the far eastern end of the Ark where a wheelbarrow could be brought in through the adjacent doors.

Collecting compost ingredients during the winter was a challenge. We gathered water hyacinths and azolla (a small aquatic fern) from the Ark's concrete fish pond, leaves accumulated over the fall, and the kitchen wastes. We managed to scavenge produce and table scraps from nearby markets and restaurants. With the farm truck we hauled "seaweed" (mostly eel grass and codium) from local beaches, as well as horse manure and spoiled hay from neighboring stables.

Between December 20, 1977, and June 3, 1978, we made four batches of compost. Collecting and unloading materials for one batch took two people from one to three hours.

All ingredients were ground up with a 7 horsepower shredder which hastened decomposition by exposing more surface area to bacteria and fungi, improved aeration and moisture control, and made handling the compost much easier. Shredding reduced the volume of plant wastes by 50–75%. The average batch of compost weighed 1,500 pounds and took two people about two hours to shred.

We controlled the proportion of various organic materials in a batch, since each kind contains different amounts of carbon and nitrogen. An optimal C/N ratio is 30:1. Microorganisms use carbon for energy and growth, and nitrogen for protein synthesis. The manure had a C/N ratio of approximately 20–25:1 (with bedding), vegetable trimmings 20–30:1, oak leaves 40–60:1, and hay 15:1 (from legumes). A moisture level of 45–60% was maintained in each batch. We wet dry materials with nutrient-rich fish pond water or manure tea as the piles were built. When the moisture levels were too high, dry materials like hay were added to absorb excess moisture. The assembly time for each batch averaged 30 minutes for two people.

The piles were kept as aerobic as possible in order to avoid putrid odors, encourage higher temperatures and promote rapid decomposition. A batch was turned every three to four days and the contents replaced in a different order to ensure that all the compost was mixed and aerated. We turned the piles on sunny days only between 10 A.M. and 2 P.M. so that the greenhouse plants could benefit from the large amounts of CO_2 being released at that time. CO_2 is essential for photosynthesis and frequently limits plant growth in greenhouses during sunny periods. Two people could turn the pile in 20–30 minutes. A pungent smell of ammonia was noticeable during several turnings. This was probably because of a low C/N ratio resulting in the loss of excess nitrogen as ammonia. At other times, a woodsy fragrance prevailed.

The ingredients for the four batches are shown in Table 1. The availability of materials determined what was used. Proportions were calculated to provide an optimal C/N ratio for the microbes.

TABLE 1 – Compost Materials

Batch 1
- 3 parts plant matter (garden and kitchen wastes)
- 1 part horse manure (25% bedding)
- ½ part compost

Batch 2
- 3 parts plant matter (seaweed, water hyacinths, hay and kitchen wastes)
- 1 part horse manure

Batch 3
- 3 parts plant matter (seaweed, leaves, and kitchen wastes)
- 1 part manure

Batch 4
- 4 parts leaves (mostly oak)
- 1 part manure
- ½ part kitchen wastes

The core temperatures of batches 2 and 4 are shown in Tables 2 and 3. As the graphs illustrate, the core temperatures in both piles remained at thermophilic temperatures (above 105°F.) for one to three weeks and then descended to ambient levels within one week. This is important as weed seeds and most pathogens are killed at high temperatures. Measurements taken at the outer edges of several batches were 2–40°F. lower than those at the core.

The volume of each batch was reduced by 10–20%. In the first two weeks, the appearance of the organic materials changed dramatically from lightly-colored and discernible pieces of seaweed, hay and leaves and other matter to a dark brown, crumbly, homogenous mixture. Over the winter, roughly one ton of the finished compost was used inside the Ark for mulches and for special soil mixes. The remainder was spread on planting beds surrounding the Ark.

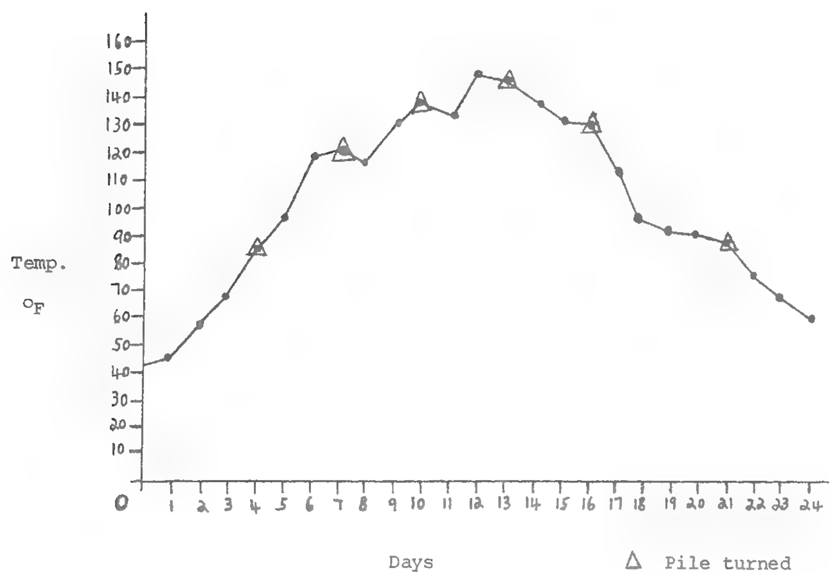


TABLE 2--Ark Compost Pile, Batch 2

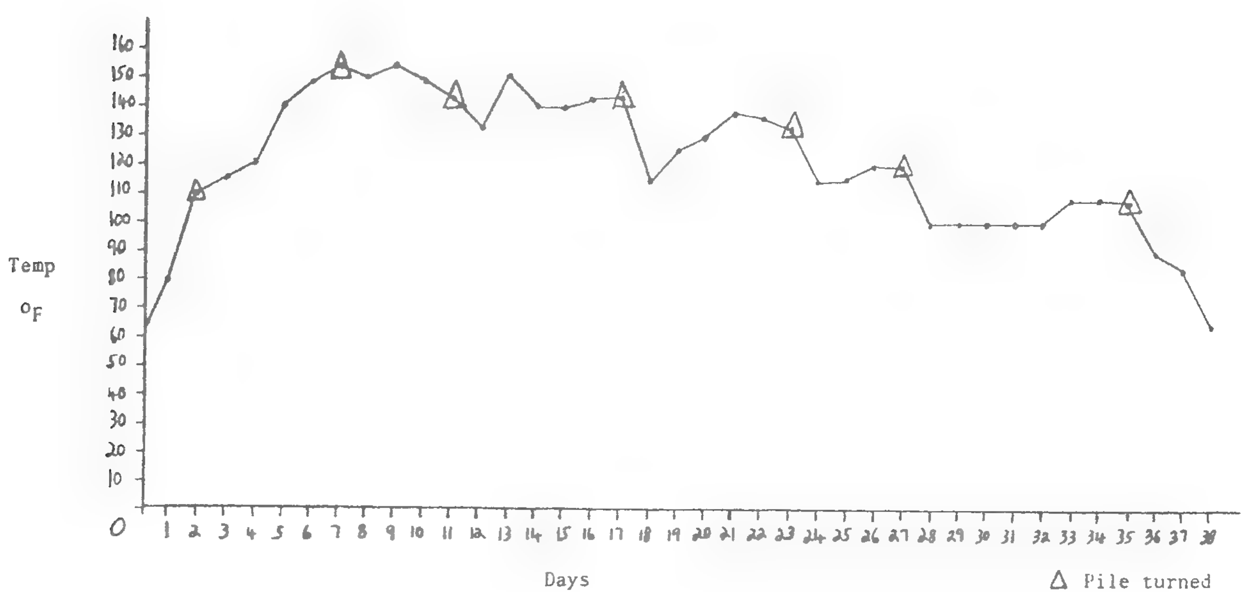


TABLE 3--Ark Compost Pile, Batch 4

A range of CO_2 and heat production rates varying from conservative to most-probable were extrapolated from several references and from data on pile weight loss (see Appendix). Calculations indicate that the compost pile might have generated 1,410–3,650 Btu. of heat and 120–315 grams of CO_2 each hour. Much of the heat and CO_2 were probably released when the pile was turned. About 124 Btu. an hour were consumed in evaporating water within the pile. The remaining 1,290–3,530 Btu. produced in an hour raised the Ark temperature by .9–2.5°F. CO_2 levels in the Ark averaged 85–650 parts per million (ppm) higher with the compost pile than without, depending on the air exchange rate in the building. Ambient outdoor CO_2 levels average around 300 ppm. Inside concentrations of CO_2 tend to drop below those outside when photosynthesis exceeds respiration, and rise above 300 ppm when respiration exceeds photosynthesis which occurs mostly during the night.

A total of five gallons of gasoline for the truck and shredder and 15 hours of physical work went into producing each batch of compost. The fuel had an approximate energy value of 635,000 Btu. That of the labor was 31,000 Btu. According to our estimated rates, 711,000–1,840,000 Btu. and 136–352 pounds of CO_2 were produced in addition to one-half ton of finished compost. This made the composting project a net energy producer.

Our composting trials were very encouraging. We provided a home for millions of microscopic friends in the compost box and catered to all of their needs. In exchange, they contributed heat and CO_2 to the Ark while rapidly converting organic wastes into a rich, fertile humus. Tending the microbe community in each batch of compost was a relatively labor-intensive process. To reduce labor costs and space requirements in the future, a large, round, wire mesh covered container would be constructed and tested instead of the compost box. It could be placed on rollers to facilitate turning, mixing and aeration.

Obtaining even higher CO_2 levels and more heat from composting requires a more sophisticated composting regime. Three or four compost piles could be established in a time series, allowing for a turning of one of the piles each day, and a concurrent release of heat and CO_2. Energy requirements for turning the compost could be reduced by terracing the northern portions of large greenhouses and letting gravity help in turning the compost. The piles or windrows could be built on the top section and subsequently moved down the terraced slope. An alternative to controlling CO_2 and heat release by turning a pile might be the controlled release of air from enclosed compost piles. Such bins might require special aeration techniques, such as internal forced air circulation. Compost systems for solar greenhouses are conceptually still in their infancy.

Appendix: Estimating Heat and Carbon Dioxide Production From Composting

The amount of heat and CO_2 production during a compost cycle will vary with materials and environmental conditions. We used two methods to estimate heat and CO_2 production rates from a one-ton batch of compost active over three weeks and then calculated the effect of these products on the Ark's atmosphere.

I. *How to Calculate CO_2 and Heat Produced by Pile*

A. *Method 1:*

1. Measure wet weight (*ww*) of uncomposted material.

   1,290 lb *ww* uncomposted material

2. CO_2 production: multiply compost *ww* (kg) by conservative estimate of CO_2 production rate (5 g CO_2/kg *ww* day).[1]

   $$(1{,}290 \text{ lb } ww) \times (0.454 \text{ kg/lb.}) = 586\ ww$$

   $$(586 \text{ kg } ww) \times (5 \text{ g } CO_2/\text{kg } ww \text{ day}) \times (.001 \text{ kg/g}) = 2.93 \text{ kg } CO_2/\text{day}$$

3. Heat production: multiply CO_2 produced (g CO_2/hr) by heat of reaction (2.9 kcal/g CO_2).[2]

   $$(2.93 \text{ kg } CO_2/\text{day}) \times (1{,}000 \text{ g/kg}) \times (1/24 \text{ day/hr}) = 122 \text{ g } CO_2/\text{hr}$$

   $$122 \text{ g } CO_2/\text{hr} \times 2.9 \text{ kcal/g } CO_2 \text{ (heat of reaction)} = 354 \text{ kcal/hr}$$

   $$(354 \text{ kcal/hr}) \times (3.97 \text{ Btu/kcal}) = 1{,}410 \text{ Btu/hr}$$

[1] Figures were compiled and synthesized from many sources by Michael Saxton in 1978 in "Production of Carbon Dioxide and Heat in Composting." These include:

K. Gray, K. Sherman, and A. Biddlestone, "Review of Composting. Part 2: The Practical Process,", *Biochemistry*, Oct. 1971, p. 26.

John Jeris and Raymond Regan, "Controlling Environmental Parameters for Optimum Composting," *Compost Science*, Vol 14, No. 1, Jan.–Feb. 1973, 14.

K. Schulze, "Rate of Oxygen Consumption and Respiratory Quotients During the Aerobic Decomposition of a Synthetic Garbage," *Compost Science*, August 1960, pp. 38–40.

K Schulze, "Continuous Thermophilic Composting," *Applied Microbiology*, 10 (1962), 115–16.

D. Suler and M. Finstein, "Effect of Temperature, Aeration, and Moisture on CO_2 Formation in Bench-Scale, Continuously Thermophilic Composting of Solid Waste," *Applied and Environmental Microbiology*, 33, No. 2 (February 1977), 348.

John Wiley, "Studies of High-Rate Composting of Garbage and Refuse," Proc. 10th Industrial Waste Conf., Purdue University, 1955, p. 311.

Wiley, "Progress Report on High-Rate Composting Studies," Proc. 11th Industrial Waste Conf., Purdue University, 1956, p. 339.

Wiley, "Progress . . ," Proc 12th Industrial Waste Conf., Purdue University, 1957, pp. 600–601.

[2] Saxton, Ibid.
Gray, Sherman, and Biddlestone, op. cit., p.28.
Wiley, Proc. 12th Industrial Waste Conf., op. cit., p.600.

B. *Method 2:*

1. Measure dry weight (*dw*) loss of organic material over compost cycle.

   (643 lb *dw* before composting) — (451 lb *dw* after composting) = 192 lb *dw* loss

2. Carbon loss: multiply *dw* lost (usually 30%–50%) by .5 to determine carbon loss.

   (192 lb) × (.5 fractional carbon loss) = 96 lb carbon lost over 21 days

3. CO_2 production: since the molecular weight (*mw*) of CO_2 is 44 and the molecular weight of C is 12, multiply C weight by 44/12 to obtain CO_2 weight.

   (44/12) × (96 lb. carbon loss) = 352 lb. CO_2 lost over 21 days

   (352 lb CO_2) × (.454 kg/lb) × (1/21 days) × (1,000 g/kg) × (1/24 days/hr) = 317 g CO_2/hr

4. Heat production: multiply CO_2 produced (g CO_2/hr) by the heat of reaction (2.9 kcal/g CO_2).

   (317 g CO_2) × (2.9 kcal/g CO_2) × (3.97 Btu/kcal) ≈ 3,650 Btu/hr

II. *How to Calculate Effects of Added Heat and CO_2 on Building's Atmosphere*

A. Heat: find out how much energy went to evaporate water from compost pile.

1. Measure water loss from pile.

   [(*ww* before) — (*dw* before)] – [(*ww* after) — (*dw* after)]

   [(1,290 lb *ww*) — (643 lb *dw*)]–[(1,040 lb *ww*) — (451 lb *dw*)] = 58 lb H_2O) lost

   (58 lb H_2O) × (.454 kg/lb) × (1,000 g/kg) = 26,300 g H_2O lost

2. To compute heat required for water evaporation, multiply water lost (total grams) by .6 kcal/g (heat of vaporization) and convert to Btu.

   (26,300 g H_2O lost) × (.6 kcal/g) × (3.97 Btu/kcal) = 62,600 Btu transferred to water vapor

3. Compute average rate of evaporative heat loss over the duration of the compost cycle. (Major portions of evaporation and heat transfer occur during turning.) Divide total Btu (21 days) for evaporation by composting period (hours).

$$\frac{62{,}600 \text{ Btu 21 days}}{504 \text{ hrs (21 days)}} = \text{124 Btu lost per hour (average) in vaporization of water}$$

$$\text{Net Btu produced/hr} = \begin{cases} 1{,}410 \text{ Btu/hr} - 124 \text{ Btu/hr} \\ = 1{,}290 \text{ Btu/hr (Method \# 1)} \\ \textit{or} \\ 3{,}650 \text{ Btu/hr} - 124 \text{ Btu/hr} \\ = 3{,}530 \text{ Btu/hr (Method \# 2)} \end{cases}$$

B. Heat: calculate effect of added Btu in building.

1. Find G factor of building $\left(\dfrac{\text{heat loss per hour}}{\text{indoor-outdoor temperature differential}} \right)$

   This accounts for heat loss through the ground, walls, ceiling, glazings and air exchange. Methods for doing this are available in many energy conservation and architectural handbooks.

   G factor of Ark is roughly 1,400 Btu/hr°F

2. Divide net Btu produced each hour (not including Btu/hr diverted to water vaporization) by the G factor (Btu/hr °F). The quotient tells the approximate average temperature increase due to the effect of the compost "furnace." This estimate does not include additional heat released upon condensation of vapor from compost.

   Method 1: $\dfrac{1{,}290 \text{ Btu/hr}}{1{,}400 \text{ Btu/hr}} = .9°F$

   Method 2: $\dfrac{3{,}530 \text{ Btu/hr}}{1{,}400 \text{ Btu/hr}} = 2.5°F$

   The air temperature in the Ark will be raised .9–2.5°F by the compost pile.

C. CO_2 production: calculate effect of added CO_2 on greenhouse atmospheric concentration.

1. Measure volume of building.

   Ark volume ≈ 17,600 ft³

2. Multiply volume by air exchange rate to find the dilution of CO_2 by infiltrating air.

   Low estimate:
   (17,600 ft³/air exchange) × (.5 air exchange/hr) = 8,800 ft³/hr

   High estimate:
   (17,600 ft³/air exchange) × (1.5 air exchange/hr) = 26,400 ft³/hr

3. Divide weight per hour of CO_2 production (grams) by its molecular weight of 44 (i.e., the weight of 6×10^{23} CO_2 molecules) to get moles per hour. Then multiply by 22.4 liters/mole to get liters per hour. Convert to cubic feet (ft³) per hour.

   CO_2 Production Estimate from Method 1:

   (122 g CO_2/hr) ÷ (44 g/mole) = 2.77 moles per hour
   (2.77 moles/hour) × (22.4 liters/mole) = 62.1 liters/hr
   (62.1 liters/hour) × (.0353 ft³/liter) = 2.2 ft³/hr

   CO_2 Production Estimate from Method 2:

   (317 g CO_2/hr) ÷ (44 g CO_2/mole) = 7.20 moles per hour
   (7.20 moles/hr) × (22.4 liters/mole) = 161 liters/hr
   (161 liters/hr) × (.0353 ft³/liter) = 5.7 ft³/hr

4. Divide the ft³/hr found in step 3 by dilution rate found in step 2 to get the volume concentration of CO_2.

   CO_2 Production Estimate from Method 1:

   (2.2 ft³/hr) ÷ (8,800 ft³/hr lower air exchange estimate)
   = .00025
   = 250 parts per million (ppm)

   (2.2 ft³/hr) ÷ (26,400 ft³/hr higher air exchange estimate)
   = .0000833
   = 83 ppm

   CO_2 Production Estimate from Method 2:

   (5.7 ft³/hr) ÷ 8,800 ft³/hr lower air exchange estimate)
   = .000648
   = 648 pm

   (5.7 ft³/hr) ÷ (26,400 ft³/hr higher air exchange estimate)
   = .000216
   = 216 ppm

The CO_2 concentration in the Ark will be raised 83–648 ppm above existing levels by the compost pile. This compares with a normal atmospheric concentration of approximately 300 ppm CO_2. Commercial greenhouse growers routinely enrich their greenhouse atmospheres with CO_2, raising levels up to 1,000–1,500 ppm. This has been shown to accelerate crop maturity and increase crop yields.

It is very difficult to measure heat, CO_2 and water production from decomposing organic materials. The actual conditions found in most compost piles can be very different from those experienced in laboratory experiments where very small qualtities or organic materials are observed under controlled conditions. The two methods outlined for estimating heat and CO_2 production rates provide "ball park" figures. Method 2 will give more accurate estimations than method 1 because it is based on the actual carbon loss of the pile whereas method 1 uses a conservative Co_2 production rate based on laboratory trials. The procedures described can also be used to estimate the size compost pile or number of piles needed to contribute a desired quantity of heat and CO_2 for a greenhouse. For example, the heat and CO_2 produced from the Ark compost pile would have a very significant effect on the atmosphere in a smaller bioshelter. To further raise the temperature and CO_2 levels in the Ark would require a series of equally sized compost piles or several larger ones. If three or four piles were constructed, each could be started at different times. This would allow one pile to be turned each day at which time large amounts of heat and CO_2 are released.

We are indebted to Michael Saxton of the University of Connecticut for his help compiling extensive references for this research. I would also like to thank Joe Seal for his assistance in calculating the estimations.

Winter Light Reflectors

Robert Sardinsky

In the Ark, microclimates are created by the strategic placement of reflective and absorptive surfaces and materials. In mid-November of 1977, we started experimenting with foil reflectors to observe their effect on plant growth. We planted two wooden boxes (2′ x 2′ x 2′) with Dwarf Siberian kale, Swiss chard, Ruby chard and three varieties of lettuce. All the plants were similar in size and leaf number. On a 2-foot-wide, 2½-foot-high plywood board nailed to the north side of one box we stapled aluminum foil to make a reflector. It increased plant growth dramatically. In two to four weeks, the plants in the reflector box were twice the size of those in the control box. At the end of December, we started picking the mature, outer leaves from all the plants. The pruned plants in the reflector box consistantly grew back faster than those in the control box. We harvested and weighed all the plants on March 10, 1978. In the reflector box a total of 5,775 grams of salad greens was produced. The control box gave us 4,900 grams. The trial demonstrated accelerated plant growth with a reflector.

In February we compared light reflected from the north wall and ceiling with the light reflected off the foil fixed behind the experimental box. Depending on the time of day, total light intensities proved 24–42% greater with the reflector.

In the Ark the lowest light levels measured were along the upper northern beds of the deep middle section. We have tried several ways of increasing light levels in this area including coating the concrete walls with white paint.[1]

[1] Several studies show the diffuse light reflected by white-painted surfaces enhances vegetable production more than specular reflectors, such as aluminum foil. Conrad Heeschen, 1978, "The Greenhouse as a Solar Collector," *The Solar Greenhouse Book*, ed. James C. McCullah, (Emmans, Pa.. Rodale Press).

PART 5—AGRICULTURE IN THE ARK

Soil Building

Kathi Ryan

The Ark is built on a sandy field. Organic matter was added to the existing dirt floor immediately after the completion of the structure. Truckloads of seaweed, leaves and manure, all of which are available locally, were dug into the growing beds. We "seeded" the above mixture with samples of soil from an oak/beech forest floor, from a meadow in an alluvial outwash in southern New England, and with "muck" from an old Cape Cod kettle hole that is now filling with a rich mixture of organic matter.

The rationale behind the seeding experiment was as follows: The bioshelter represents a totally new environment. Ecological agriculture is possible only if a dynamic ecosystem capable of dealing with pests and animals is established and allowed to mature over time. Within diverse soil associations there may exist the bacterial, viral, fungal, protozoan and invertebrate animal associations which together could create the basis of an ecosystem unique to bioshelters. Seeding in this context is supplying the genetic basis for the development of new ecosystems for growing food. Every year, at the time of the fall transition, approximately a ton of compost is added and dug in. Top applications of compost are applied as needed throughout the year. Organic matter necessary for the structure of the soil as well as for fertility, is broken down rapidly under conditions of high heat and humidity.

Soil Chemistry and Structure

Colleen Armstrong

Bedding Soil. All three levels of agricultural plots have similar soil structure. For three consecutive fall seasons compost has been worked into the top foot (12 in.) of each plot. The texture is a blend of loam and sand. Compared to the surrounding local soils, the Ark's soil is high in humus content, 7%. The combination of leaf mold, compost and sandy substrate offers very good percolation when watering. Through the U. of Mass. Extension Service, Waltham Experimental Station and Woods End Laboratory in Maine, several soil samples have been examined since 1977. Over the two years, the pH has fluctuated between 6.5 and 7.2. For most vegetable production, these readings are ideal; a neutral soil has a pH of 7.0. Most vegetables prefer the slightest acidic soil in the range of 6.5–7.0. Looking at the macro-nutrients required for good growth, the Ark again is rich with these elements.

Soil Report, Woods End Laboratory

	November 1977	*November 1978*
Nitrogen Annual Release	M	M
Phosphorus	MH	MH
Potassium	M	MH
Magnesium	M	H
Calcium	MH	M

(M) Medium (MH) Medium-High (H) High
Both Nitrogen and Phosphorus are analyzed as nutrient anions. Potassium, Magnesium and Calcium are analyzed as exchangeable cations.

With each soil report from the Woods End Laboratory, we receive a colorful humus chromatograph, a visual representation of the composition of the organic matter. Along with it is a graph indicating how well the soil is providing the necessary nutrients. Many factors are considered: quantity and diversity of the organic matter, diversity of soil organisms, mineral content, moisture and temperature. The Ark's soil is described as a "Mull Humus" with rapid mineralization, a moderate amount of carbonates, which affects the determination of cation exchange capacity; microflora present; organic and clay constituents, all producing a good soil structure with an adequate reserve of carbonaceous material.

There has been concern for a high concentration of the total soluble salts in the soil in the Ark since natural phenomena like rainfall do not occur to leach the soil thoroughly. When interpreting the data received from the laboratory, a total soluble salt index above 100 is dangerous for crop productivity. We have found that compost can be well above this index and when soil reports indicate a high soluble salt content in the soil with fresh compost we leach the soil. Sporadic leach was necessary during the fall-1978 and winter-1979 seasons.

Seed Germination. Although this is a secret recipe, it has proven very successful for seed germination. No matter what quantity of soil you desire, mix together one part sifted peat/one part sifted compost[1]/one part sand, perlite or vermiculite. The vermiculite will absorb water (sand and perlite do not) hence the soil medium will be heavier. Add water when ready to seed. If I am seeding very tiny, minuscule seeds, which need a light medium to send roots and root hairs through, I may use one-hundred percent vermiculite. It has worked well with celery, parsley, allysum and other smallish seeds.

After the seeds have germinated, it is often necessary to transplant them into a second medium before their final destiny into the bedding soil. This soil is usually many combinations. The best has proven to be a blend of one part old seeding soil mix to one part sifted compost. At this time in the seedling's life, the young plant is able to utilize the nutrients in the composted soil.

Varietal Testing of Domestic and Dutch Lettuce Varieties

Kathi Ryan

Over the past three winters, we have tested many different varieties of vegetables, seeking those that are highly adapted to the environment created by solar greenhouses. We have found that vegetable varieties bred especially for greenhouse production are better adapted to the lower and higher humidity present in a greenhouse during the winter months. Consequently we have had less fungus and mold problems, and the plants have been sturdy and healthy. In comparing greenhouse varieties of lettuce from Holland with domestic varieties last winter (1977/78), we found that the Dutch varieties out-yielded most of the others and that the heads were of exquisite commercial quality. (See Table 1.)

We have just begun to work with Dutch varieties of tomatoes with the same positive observations. This spring we will be growing two types as part of an economic study.

During the late part of November, through December and into January, the light levels in the greenhouse are low and growth slows to a minimum. We have found several crops that continue to grow well and to produce food during this time, despite these conditions. Endive and New Zealand spinach, both of higher nutritional quality than lettuce, do well at this time.

Other crops that grow successfully during the winter months are parsley, kale, chard, celery, chinese cabbage, dill, cole crops and of course, lettuce.

[1] If good foresight is used, the compost material should be leached, limed and aged before use.

TABLE 1—Varietal Testing 1977 & 1978

Seeded 9/5
Transplanted 10/3
Harvested 11/21
Number of Plants 10

Domestic Varieties	*Total Weight*	*Dutch Varieties*	*Total Weight*
Bibb	1043 g	Deci-Miner	973 g
Grand Rapids	1106 g	Decisco	1035 g
Great Lakes	816 g	Rossini	2396 g
Salad Bowl	1308 g	Ravel	2088 g
Early Prizehead	1217 g	Mistra	1730 g

Seeded 11/3
Transplanted 12/11
Harvested 3/8
Number of Plants 5

Dutch Varieties	*Total Weight*	*Dutch Varieties*	*Total Weight*
Bibb	470 g	Mistra	497 g
Grand Rapids	203 g	Ravel	678 g
Salad Bowl	210 g	Rossini	520 g
Early Prizehead	471 g	Decisco	499 g

The Dutch varieties can be obtained from: Kisk Zwaan, Zaadhellt en Zaadhendel, DeLier, Holland.

Tomatoes

Kathi Ryan

Twenty-four plants, twelve of each variety, were planted at an interspace of 18". The plot had a total growing area of 55 sq. ft. The varieties chosen, Tropic or regular size and Small Fry, a cherry variety, were seeds we had on hand and were not chosen for any particular quality. They both turned out to bear tasty fruit.

Seeds were started in the basement of the farmhouse (1–30–78) where the temperature is warm and stable. They were later transplanted to individual milk cartons and left in the basement under grow lamps. Three weeks later (3–20–78) they were transplanted into the ground in Ark. Each plant was given a foliar feeding of seaweed extract at the time of transplant and every two weeks thereafter.

Once the soil warmed to desirable temperatures the plot was mulched with seaweed. Periodically, as plants began to bear fruit, applications of manure or comfrey tea were given. The whitefly population that invaded the tomato plot was controlled by the parasitic wasp, *Encarsia formosa*. The experiment was terminated when tomatoes from our outdoor gardens began to compete with those from the Ark.

	Small Fry	*Tropic*
Seeded:	1-30-78	1-30-78
Transplanted:	3-20-78	3-20-78
First Flowers:	4-10-78	4-28-78
First Ripe Fruit:	5-28-78	6-19-78
Peak Production:	7-19-78	8- 8-78
Total Weights:	34 lbs.	98 lbs.

This represents yields of up to four pounds per square foot for the Tropic variety in the less than two-month experimental cropping period. This is comparable to commercial greenhouse production.

Present Work and Future Plans

Kathi Ryan

We will be testing two varieties of greenhouse-bred tomatoes in production trials. One of these varieties, Lito, was grown in the fall of 1978, producing fruit until late November and ripening continually into January. These plants are better adapted than those we grew previously to greenhouse conditions and are fairly disease-resistant.

Onto the established Lito rootstock presently in the greenhouse, we will graft plants seeded for spring production and compare yields with those plants that are not grafted but instead set directly in the ground.

An experiment carried out at the Ark on Prince Edward Island compared double-pruning tomatoes with those grown on a single stem. To double-prune a tomato, the third sucker is allowed to grow and become its own stem, thereby creating two main stems instead of the conventional one. On P.E.I. they found the yields from this method of pruning to be more than double. We will be using this method for Lito and Type 127, both from Rijk Zwaan Co. in Holland. Those varieties used successfully on P.E.I. were Vendor and Tuck Queen from Stokes Seed Co.

Another crop of economic value is the cucumber. Our past experience (summer of 1977) with cucumbers in the Ark was discouraging due to their susceptibility to whitefly. Since then, we have brought the whiteflies under control with the wasp *Encarsia formosa* and several other control agents.

This year the Ark will be producing vegetable, flower and herb seedlings for the entire garden and surrounding landscape. Between March and mid-May seedlings of tomatoes, eggplants and peppers will be grown in the structure for subsequent outdoor planting. A mist propagation system will be installed for fruit and nut tree seedling production.

Insects in the Ark

Colleen Armstrong

Insects play an important role in the ecosystem of the Ark. The semitropical climate of the building encourages prolific populations of common greenhouse pests. But this also makes possible the establishment of native and exotic predators and parasites to regulate pest populations. Inside the Ark, temperature, relative humidity, light intensity, photoperiod, the vigor of the seasonal vegetation and other factors as

well, all affect the rate of development of individual insect populations. And to the chagrin of my pesty friends, we too are a part of the Ark community and our role as pest managers must be as dynamic as that of the ecosystem of the Ark. Our intrusions on their development are both physical and biological. We are engaged in the process of information gathering, monitoring numbers of insect pests, evaluating the agricultural environment, and finally, deciding what actions to take. In this section I will focus on the important biological controls in our semi-closed ecosystem, natural and introduced.

In the spring of 1977, *Trialeurodes vaporariorum*, a greenhouse whitefly infested young tomato plants inside the Ark. Whiteflies feed on a variety of plants, vegetable and ornamental. In greenhouses they favor tomatoes, cucurbits, lantanas and fuschias. The lifespan of an adult whitefly is 30–40 days, during which time a female insect may lay as many as 500 eggs. There are six stages in the life cycle that include the egg, three larval stages (often called instars), pupae and adult. The larvae look like scales; oval, translucent, flat discs. Their rate of development is a function of temperature. At 15°C. (59°F.), maturation from egg to adult takes four weeks; at 21°C. (70°F.) complete development takes three weeks.

Whiteflies are well known for the damage they cause to food and ornamental crops. Both adult and larva suck essential plant juices and excrete a sticky "honeydew" that coats leaf surfaces. You can imagine how discouraging it is to have a three-month jump on normal tomato production and then to lose your crop to a dainty white winged creature 1.5 mm. long!

A Canadian biologist, Dr. R. J. McClanahan is one of several entomologists who have been investigating the parasitism of the whitefly by a minute wasp, *Encarsia formosa*. The female wasp oviposits one egg in a whitefly scale, usually during the second or third larval stage. Within a few days, the egg gives rise to its own larva, which consumes the whitefly scale from within, turning the hard outer coat black. When development is complete, an adult wasp emerges from the parasitized scale. Like that of its host, *Encarsia formosa*'s rate of development varies with temperature. At 18°C. (65°F.), both host and parasite mature from egg to adult in 31 days. The *Encarsia*'s life cycle is shortest and its oviposition rate is highest between 24°–27°C. (75°–81°F.). The whitefly is not as fecund at 24°C. (75°F.) however as it is at a lower temperature. At warm temperatures (24°C. and above), the oviposition rate begins to decrease.

Table 2 shows its development from egg to adult of whitefly and *E. formosa*.

In June 1977, Dr. McClanahan sent us 2,000 parasitized whitefly scales to be dispersed among the infected crops. The parasitized scales came on tobacco leaves and were pinned to the underside of tomatoes' lower foliage. Within two weeks, we found parasitized, blackened scales on our own plants, although actually reducing the numbers of whiteflies took time. In late July, Dr. McClanahan sent an additional 5,000 parasitized scales to raise our proportion of *Encarsia* to that of the abundant whiteflies. The suggested effective proportion is one parasite to thirty whiteflies. The second introduction provided enough parasites to check the population of pests. Daily temperatures inside the Ark at this time averaged between 25°–29°C. (77°–84°F.) which allowed the parasite to multiply quickly. By August, the host population had been drastically reduced and was no longer a threat to tomato production.

For our first attempt at introducing a specific and exotic insect into the bioshelter, the *Encarsia* was most effective as a biological agent. Being a tropical species, we expected to lose our wasp friends in the cool winter months. An unanticipated surprise came in March, 1978, when the familiar black, parasitized scales were discovered on an unruly tomato plant above the rock storage area. Indeed, the *Encarsia* had prevailed through the winter and found a home in the Ark. Throughout the spring months, we tallied the number of whitefly scales and redistributed parasitized scales on the 1978

TABLE 2—Autecology of Trialeurodes *and* Encarsia *with respect to temperature*

	18° C.		24° C.		27° C.	
	Tria.	*Encarsia*	*Tria.*	*Encarsia*	*Tria.*	*Encarsia*
Longevity (days)	42.5	27.0	17.2	15.7	8.3	8.2
Fecundity (eggs ♀)	319.6	28.2	123.9	32.7	29.5	30.5
Rate of Oviposition (eggs ♀ day)	8.2	1.7	7.5	2.7	5.1	5.3
Sterility (per cent)	5.7	5.7	8.6	2.9	18.2	
Length of development (days)	31.5	31.1	24.7	15.1	22.8	11.9
Host Susceptible to Parasitization (days)	16		13		11	
Mortality (per cent)	6.6		16.6	–	32.4	—

Thomas Burnett, "The Effects of Temperature on an Insect Host Parasite Population," *Ecology*, 30, No. 2 (April 30): 113–33.

tomato crop. In the spring and summer, the whitefly population never reached levels that would create economic losses. I must add that the *Encarsia* operation was successful with a minimum of assistance. We suggest that the home-greenhouse gardener could use *Encarsia formosa* as an effective means of control over greenhouse whitefly, provided a high enough temperature is maintained.

Most likely, aphids are the bane of any grower's existence. Countless numbers of species suck on leaves, petioles, stems, buds and flowers. Many are not plant specific for their food; they do prefer succulent, tender, young plant tissue. Aphids reproduce at a phenomenal rate; some generations have both winged and unwinged forms. They are most prolific in the springtime when sexually produced eggs hatch and new aphids begin to bear their young alive. In our gardens or even in larger agricultural areas, natural predators and parasites contribute to aphid control. The Ark, being a semi-closed ecosystem, may limit the number of natural, beneficial insects entering the building. However, over the past two years, we have noticed insect activities that have repressed aphid populations. Individually, they did not demonstrate a significant amount of control, although their combined efforts exhibited potential for integrated control. In this case we use integrated in the sense of blending physical, mechanical and biological agents in an effort to subdue this greenhouse pest.

Myzus persicae, the green peach aphid is the predominant aphid species residing in the Ark. Unfortunately, they select their food from a wide range of vegetables (brassicas, lettuce, celery, carrots, and beets) along with annual and perennial flowering plants. Usually, they have a light green body approximately 2 mm. long. The female may reproduce asexually and her nymphs may either develop wings or remain wingless. In the spring, at temperatures between 15°–20°C. (59°–68°F.), each generation could possibly increase by seventyfold. A tough act to beat!

In the beginning of 1978, green peach aphids were discovered on vegetable stems and foilage on all levels in the Ark. The degree of infestation varied from plant to plant. Considering the presence of this pest, vegetable productivity continued to be remarkably high. Once a week, particular plants (Chinese cabbage, lettuce, kale, beets, chard and celery) were checked for the numbers of aphids on a 50 cm^2 surface. They were described as winged or unwinged, nymph or adult. On susceptible plants, we observed a rise in their birth rate and intervened when the aphid population became intolerably high. We washed the plants with water and occasionally a biodegradable soap.

Observing the aphids revealed several fascinating natural controls. A fungus, *Entomophthora* that thrives in a cool, humid environment and feeds on the green peach aphid was discovered to be a control agent. The fungus grows within the aphid's body and transforms its host's gelatinous tissues into a mass of short fibers called hyphae. After the fungi break down the cellular structures, the insect dies and the reproductive hyphae push out through the shell of the aphid's remains, transforming it into a fuzzy, cream-colored dot. The reproductive hyphae, called conidia release spores to be carried off by the wind or water. In the cool winter months, the parasitic fungus can be seen throughout the Ark, localized in the dampest areas. During January and February, as the aphid birth rate begins to accelerate, the *Entomophthorous* fungi infect clusters of aphids, resulting in mortality to both nymphs and adults. However, as the year progresses, the bioshelter acquires enough heat to retard the fungi's growth.

On the other hand, longer days and warmer temperatures encouraged the aphids to bear more young. As the pest population multiplied, an insect parasite of the green peach aphid was identified inside the bioshelter. In February, a mummified aphid shell was discovered attached to a nasturtium leaf. A few days later, a tiny wasp emerged and began to sting nearby aphids. The aphid parasite was identified as *Aphidius matricariae*. Research in Europe and California has shown *A. matricariae* to be an effective biological agent for control of aphids, especially green peach aphids. The parasitic insect lays its eggs inside her host. The egg hatches and the subsequent larva feeds of the aphid's fat tissues. After several larval molts, the pupae rests inside the shell of the aphid, which has been transformed into a hard copper-brown case. About two weeks later, it finally emerges as an adult wasp, close to 2 mm. in length. A female wasp is capable of laying more than one hundred eggs. In the Ark, parasitism rate was low, with 5% of the aphid population parasitized by *A. matricariae*.

Both the *Endomophthora* fungus and *Aphidius* wasp are good illustrations of natural enemies of *M. persicae*. Even though the numbers of parasites were insufficient to totally check the explosive population of aphids, their presence contributed to the pest's mortality rate. In the future, additional parasites such as *A. matricariae* will be released to obtain a higher percentage of parasitism.

Now, what about aphid predators? Couldn't they be at least as efficient as parasites? The ladybird beetle, *Hippodamia convergens* is a fine example of a common aphid predator. The colorful larva has a voracious appetite, and is capable of consuming as many as forty aphids in one hour. Adult ladybird beetles may live for an entire year and travel many miles. In addition to the ladybird beetle, syrphid fly larva, many spiders and damsel flies are predators of aphids and all reside in the Ark. The most frequently seen is the yellow syrphid fly larvae; however, when compared to the number of aphids, their presence is occasional and their populations are small. It would be to our advantage to further

establish a diverse community of beneficial insects. Biological control of pests, i.e. *M. persicae*, could be spread among different insect parasites and predators. Fewer mechanical methods would be necessary and the control itself would be more effective.

Not unlike other greenhouses, the Ark has a variety of pests that are associated with certain seasons of the year. Red spider mite, *Tetranychus urticae*, arrives with the summer months. To date, their damage has been small and restricted to ornamental crops. As insurance against red spider mites reaching destructive levels, we have released a predatory mite, *Phytosielus persimilis* that has shown effective control over this pest in Canadian research. Yet another nuisance are thrips, mainly *Thrips tabaci.* This soft-bodied pest feeds on leaf tissue, sucking out cell contents. Their damage can be recognized by a silver sheen on the leaf surface. Actually, the appearance of sheen is given by air occupying the empty space of the cell structure. Thrips prefer a warm climate. Avoiding susceptible plants such as nasturtiums will aid in their control. Another method to discourage thrip propagation can be eliminating annual crops when they have reached maturity cutting short the thrip life cycle.

Overall, taken as an environment, nothing can compare to the Ark. Its nature is unique. In theory, people created it, but as an entity, it evolves beyond our expectations. After reviewing important insect activity, advantageous or otherwise, I anticipate a relatively stable domain. With each season, population swings and outbreaks decrease in intensity and frequency. The increasing stability over time suggests that an ecological succession of sorts is taking place. How long it will take to reach a steady state and how often we must interfere remains an unknown. Total biological control of insect pests may never happen. Too many abiotic factors shift the scales; especially in the Ark's ecosystem, nature itself is the strongest regulator of population dynamics.

Nevertheless, the Ark holds vast potential for practice in methods of biological control. Practically speaking, it must insure its reliability as an economic enterprise. We have seen natural phenomena such as the *Endomophthora* fungi and *A. matricariae* contribute to aphid mortality. *Encarsia formosa* has been a successful biological agent specifically introduced for the control of greenhouse whitefly. The following strategies could optimize the biological control of insect pests in an integrated management system. First, begin a program to collect native beneficial insects. Green and brown lacewings, ladybird beetles, various ground beetles, syrphid flies, spiders and various parasitic wasps would be excellent candidates. Second, select the most successful predators and parasites to breed in a small insectary for the New Alchemy bioshelters and farm. These insects could be released when their control was needed. Third, use vegetable varieties that are resistant to insects by their appearance or physical conditions. In this vein, continue to develop cultural techniques for vegetable production that can be integrated with biological methods for the control of insect pests. Finally, experiment and create an insect ecology that provides the habitat for the Ark's beneficial insect community. Practical pest management takes a lot of effort, but in the long run, we will continue to reap the benefits.

PART 6—A REVIEW OF AQUACULTURE IN THE ARK

Ron Zweig

The initial idea and practice of raising fish in solar-algae ponds has revealed more about aquaculture than we expected. The 630 gallon highly translucent fiberglass cylinders five feet in diameter and in height have increased our understanding of the nature of aquatic ecosystems. At first the idea was to maximize the amount of solar energy entering a body of water. This increased the primary productivity in the water column. The dense algal blooms (greater than 10^6 cells per ml.) provided an efficient substrate for the absorption of sunlight by acting as passive solar collectors. The phytoplankton was also a rich source of food for a phytophagous fish, tilapia, whose filter feeding behavior will also prevent algal senescence.

In the first summer trial in 1975, a pond was set up outdoors in the open. We followed a semi-conventional approach to closed-system aquaculture and installed an oyster shell bacterial filter. The hope was to oxidize the toxic ammonia secreted by the fish, to keep it within a safe range for the fish and to prevent the pH of the water from becoming acidic. The ponds were inoculated with samples of algae collected from a number of ponds on Cape Cod. One hundred tilapia, *Sarotherodon aureus,* fingerlings were added to the pond. A dense algal bloom followed. The colorless pond became a brilliant green. The temperature in the pond rose to nearly 30°C. and remained close to this through July, August, and the first half of September. The most remarkable aspect of this was that these temperatures are believed optimal for tilapia growth. The pH also remained basic until early October, when on a rainy, dark day the pond became unstable and the phytoplankton population collapsed. The pond changed from rich green color to brown, but the entire fish population survived attesting to the hardiness of the tilapia. This near disaster pointed out that more ecologically complete solar aquaculture systems were needed.

Consequently, we removed the oxygen-draining shell filters and exchanged half the water in the ponds. Since the pH of the water was higher than the natural equilibrium pH of the shells we began to suspect they were unnecessary. The bacteria on the shells were creating an intensive oxygen drain on the pond. Within a week a new algal population became established, and the pond returned to its former brilliant green color.

After exploring the literature, we learned that several species of green algae are capable of metabolizing ammonia directly from the pond water. This led us to believe that a phytoplankton-based aquatic ecosystem could be designed using only the contained productive organisms to control both physical and chemical problems. The algae alone proved useful as (1) a feed for phytophagous food organisms, (2) oxygenators of the water through photosynthesis, (3) purifiers of the water through directly metabolizing toxic fish wastes, and (4) micro-heat exchangers through absorbing solar energy.

With the coming of winter, we decided to test a pond outdoors replacing the tilapia with a population of temperate fish species—the mirror carp and the Chinese silver and big head carps. An additional layer of fiberglass was added to the pond wall. A 1 cm. air space separated the inner and outer layers so it functioned as a thermal weather pane. Also, the pond was covered with a double-paned geodesic lid. Later a parabolic reflector was built to the north of the pond to increase the amount of light entering it and to protect it from the frigid north winds. With these additions, we crossed our fingers and hoped we wouldn't have to terminate the experiment by breaking through a column of ice to retrieve the fish.

To our amazement the water temperature never dropped below 4°C. even with the outside air temperatures dropping to −21°C. The average temperatures achieved in this solar-algae pond where well above those in the subsurface ponds within the Six-Pack and Dome structures. Besides the important results in regard to thermal energetics, the fish in the pond not only survived but also increased in weight.

At the time of the winter solar pond trial, the designing of the Cape Cod Ark was in progress. The significance of the solar energy absorption characteristics of the outdoor solar pond won them a position in the architecture of the building. They were incorporated as passive solar collectors and fish production units within the structure. An exterior reflective courtyard was designed for the building. The full potential of the ponds both for fish productivity and as solar collectors had yet to be evaluated. The next summer's experiments were designed with this in mind.

The first production trial for the summer of 1976 used the pond with the reflector that we had built the winter before. The Ark was still under construction. In this experiment, tilapia, mirror carp, and the Chinese silver and big head carps were raised together. The net productivity was 6.98 kg. during the 98-day trial. This figure was nearly ten times greater per unit surface area or volume than ever reported for a standing body of water. The conversion ratio was 1.0, meaning that one pound dry weight of feed produced one pound of fish. Subsequent single species or monoculture experiments have not yielded as high a combination of growth and conversion rates, although they are relatively close. Through improved management and species selection the true potential is still to be realized.

We began an intensive evaluation with the 23 ponds available to us within the Ark complex. These experiments were to include the linking of ponds in a "solar river" design and the testing of different fish species and densities. We embarked on this systematically with a series of controlled experiments. We chose to work toward the development of an ecological model of the ponds that would be used as a tool to assist in maximizing productivity. For this, we realized we'd need a means to monitor the ponds and to analyze the data.

Toward the end of the summer of 1976, a preliminary analysis of the Dome aquaculture pool was undertaken. This led us to conclude that the development of our aquaculture would require the assistance of a computer-based data acquisition system. The project we devised would not only supply us with a means of increased food productivity but also put our work in the realm of basic ecological research. The proposal was submitted to the National Science Foundation. The grant was approved.

The impact of this funding was three-fold. First it offered us the potential of three years' support. This allowed for the design of a series of systematic experiments. Secondly, we were able to bring in a water chemist and systems analyst who would be helpful with all the Institute's research. Third, and perhaps most important, was the creation of a forum composed of a coordinated research team enabling us to focus on the aquatic systems at several levels. We chose two parallel courses of investigation. One was to evaluate the solar-algae ponds with sophisticated monitoring instruments, and the second to compare these results with information gained from human observation, e.g., color, smell, fish behavior, etc. The results from this will be used to develop a simple guide to fish culture which will employ the use of instruments no more complex than a Secchi disc, a feeding routine for differing culture designs, and a management procedure to anticipate and alleviate problems that may evolve. We also hope to gain a deeper understanding of natural ecosystems from this work. To date, several important criteria have been elucidated.

The most important aspect of present research is that it has broadened our perspective of raising fish in

small aquatic systems. At first, we thought it was critical to monitor ammonia in the ponds. As already mentioned, the compound is toxic to fish. The significance of the presence of this compound proves to be greater than just an indicator of the fishes' health. It is also an indicator of the stability of the ecology within a pond. We have learned this through a sequential analysis of the water chemistry through the course of a production trial. (We have expanded the number of measured factors to include ammonia, nitrite, nitrate, phosphate, sulfide, sulfate, alkalinity, turbidity, pH, dissolved oxygen, solar radiation, and temperature.) If, for instance, significant quantities of ammonia are present, it becomes likely that a series of unstable chemical fluctuations will follow; i.e. a build-up of nitrite followed by nitrate. This is the sequence in the oxidation reactions following ammonia by the *Nitrosomonas* and *Nitrobacter* bacteria. The direct impact of these compounds upon fish growth and the evolution of microorganisms associated with them is a puzzle we are currently attempting to piece together. (See Aquaculture section of this *Journal*.) These factors allow us now to perceive fish culture in terms of the entire ecology of the culture ponds. This perspective brought us to another important consideration in pond management and maximization of fish productivity.

It is important not to base calculations for supplementary feeding solely on a percentage of the fish biomass. It is also necessary to consider the nutrient loading capability of the ecosystem. Excessive feeding loads the pond, and the capacity of the living organisms to assimilate the fish waste products is reduced. With regard to the build-up of ammonia, the nitrogen content of a specific feed has a direct correlation to the amount of nitrogen compounds released into the system in the fish wastes. The efficiency of assimilation has proven to be different between species. It is, therefore, necessary to match the kind of feeds and rate of feeding with the organisms present in the pond, and not to exceed the loading capabilities, regardless of fish biomass. A particular polyculture strategy in a finite volume of water will have its own inherent maximum feeding rate depending upon the size and nature of the ecosystem. We are working on several design possibilities to optimize productivity.

Four strategies are being considered. An integration of certain factors from all four will probably lead to the best design. The first consideration is the choice of species to be cultured. These should be selected to optimize the nutrients available at the different trophic levels in the ponds, as well as feeds that are added. These include in the solar-algae ponds the phytoplankton, solid fish wastes and sediments, and sessile organisms that grow on the sides of the pond. The second strategy is to match the kind and quantity of the feeds with the efficiency of their assimilation by the living organisms within the pond. The third is to investigate a recirculating hydroponics design to utilize excess wastes that build up during an accelerated feeding regime. This may increase the productivity of a pond through redirecting nutrients that can cause instability by stabilizing algae populations through nutrient competition, space, etc. The last strategy would be either an incremental or constant slow dilution of the pond water from a fresh supply. This replaced water could be used to provide nutrients for agriculture through irrigation. The composite design of the Cape Cod Ark makes this tactic possible inside the building.

The solar-algae ponds, therefore, have several uses in bioshelter design. They provide a means of passive solar energy collection and aquaculture inside. They can be used to provide fish waste nutrients for agriculture through irrigation, and at the same time reduce the chance of thermal shock to plant roots by prewarming the water. At this time, the potential for using the pond sediments for methane generation is also being considered

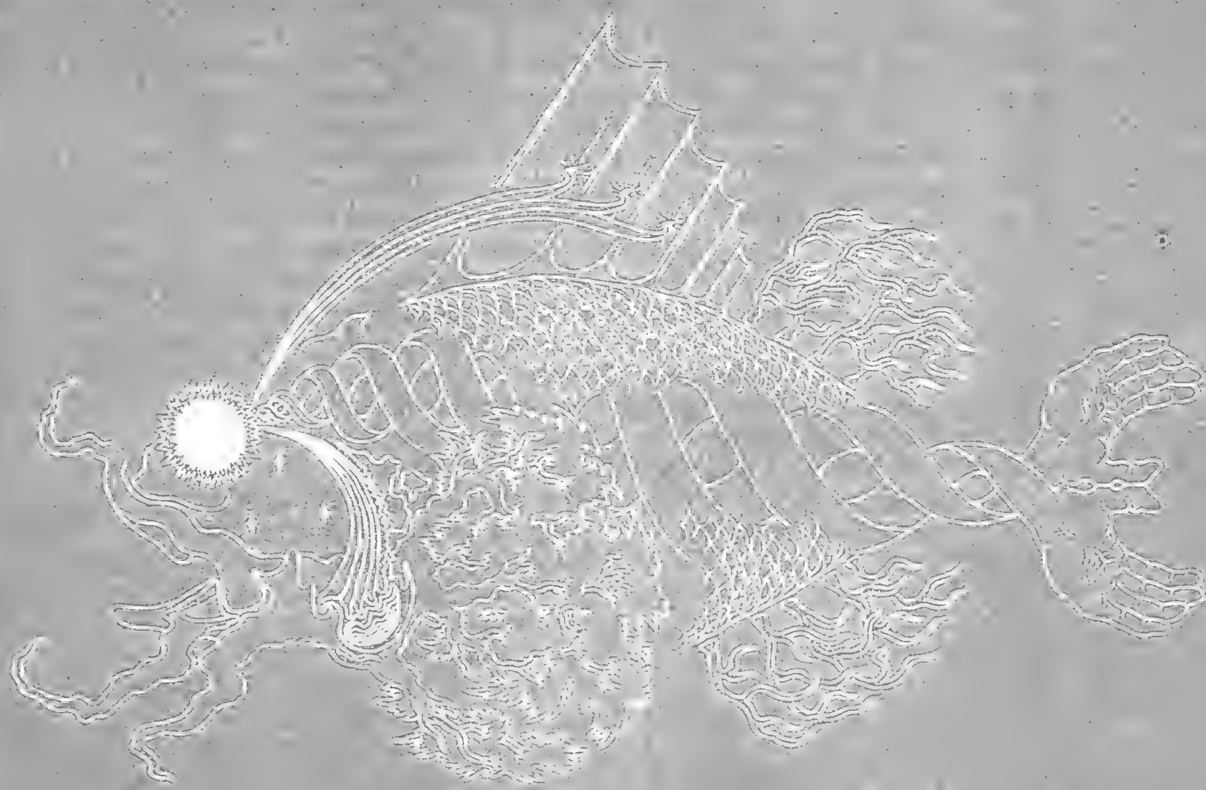
The experience we've gained in evaluating solar-algae pond aquaculture for the Cape Cod Ark has been manyfold. The benefits from their integration in architecture proved to be significant. The research and daily contact with these aquatic systems has increased our knowledge and perspective of the nature of ecosystems. It is bringing us closer to understanding the dynamics and sensitivity of the biosphere, a semi-closed ecosystem of which we are all a part.

POSTSCRIPT

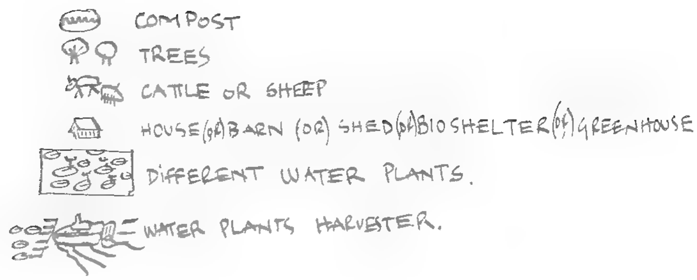
John Todd

It goes without saying that the presence of the Ark at New Alchemy has changed how all of us feel about the future. Ultimately, Arks and the thinking that they engender are the best antinuclear devices we can conceive. They envision a world based on the sun, wind, and biofuels; a world on a human scale within which each of us helps orchestrate the forces that sustain us, and a human community that works in a sacred harmony with the living world upon which we ultimately depend.

Photo by John Todd



Explorations



This section of the Journal *traditionally has been a mixed bag, a space in which New Alchemists and their friends could pursue their personal quests in areas that did not necessarily fall definitively into any of our other categories. This time, with "Sensitive Societies," Ron Zweig extends the thinking that he developed in an earlier article, entitled "Bioshelters as Organisms," to social applications of a biological analogy for the present mechanistic social structure. Like Lewis Thomas, he is a firm believer in those "spectacular symbionts —the chloroplasts and mitochondria tapping the sun and making use of it in aid of all the rest of us."*

In "Near Horizon Economics," Joe Seale indicates the disparities in thought between proponents of continued economic growth and those of us who come to weigh our actions in the judgment of coming generations, contrasting the traditional economic and the ecological ethic.

With Jeff Parkin's interview of Sava Morgan, the puzzling over learning which underlies so much of what we do is tackled straight on. Sava has been struggling for many years to find means by which one can learn what Gregory Bateson has called "ecology of mind." The medium that she has found most satisfactory for doing so is art, specifically drawing and painting. Most of the people who have worked with her maintain that she is the best art teacher they have had. Jeff, who has studied with her, shares this view and through his interview with her some of the reasons for it become apparent.

The last article is the transcript of a talk that was given by Francisco Varela at the Lindisfarne Fellows Conference in New York in June 1978 and was subsequently reprinted in the Lindisfarne Letter (8). I was profoundly impressed by the talk on first hearing it at Lindisfarne, equally so on rereading it. Bill Thompson has always warned that no matter how well intentioned one's acts, they contain the seeds of their opposite or shadow side. As the politics of ecology become more heated with the debate over nuclear energy and fuel shortages, the lesson of Francisco's experience of the political polarization that developed during the Allende years in Chile seems to me particularly apt. Weathering what is bound to be a fairly stormy transitional period in the next few years may depend less on vigorous partisanship than on learning to think, in as much as we can, about the entirety of the situation, upon what Varela and Bateson call our epistemology.

NJT

Sensitive Societies: A Biological Perspective

Ron Zweig

"How can your philosophy of decentralization and ecology be concretized into a useful framework for society?" This question was posed by a visitor one Saturday at a workshop at New Alchemy led by Murray Bookchin. I found the question of interest for two reasons: the first being the man's selection of words, and the second, the theme implicit in his question.

It is important to consider the way in which a question is asked to be able to give an answer with the proper perspective. In the case of our visitor the rigidness of his terminology called for an extensive reply. In pursuing the idea of an ecological perspective for social design, the word "concretize" creates some difficulty because the very general nature of the question implies a universal solution, applicable to diverse social climates which, even in North America, are the case. Such a concept without flexibility for the particularities of region would, in itself, be unecological. The integrating of decentralization with ecological principles is critical in seeking a viable approach to design for human communities.

This becomes evident in considering the various

bioregions of the continents throughout the world. The "biogeographical provinces" which Dasmond and Udvardy's work illustrates indicate the necessity for specific evaluation of a particular region as to its resources and climate, assets and limitations.[1] With these criteria in mind, the paradigm for an ecologically based human society, one that adapts with minimal impact into the larger ecosystem, can be formed. The design principles inherent in biological systems offer an excellent early foundation for an enduring social structure. Many of these are found consistently in all living organisms, and considerable data from research on individual cells to that of ecosystems has been documented in scientific literature.

Cells are the modular units, or simplest forms, of life. Essentially, cellular processes are miniature analogs of the mechanisms of larger life forms. A remarkable number of the better designs for human community have been engineered to parallel cellular functions. The sections following will describe some of the potential for the adaptation of the principles of cellular processes, but before doing so I should like to restate the question that prompted this inquiry into one that is more workable. "How can we use the principles of decentralization and ecology to restructure a guide for human society?"

THE PARADIGM OF THE CELL

The analogy of a cell to larger systems has been used before to increase our comprehension of living systems. In *The Lives of the Cell*, Lewis Thomas portrays the earth as reflecting the image of the living cell.[2] Lynn Margulis and James Lovelock, in their *Gaia* hypothesis,[3] look at the earth as a single ecosystem—the biosphere—and postulate that a deleterious impact on any portion of it would threaten the health of the entire planet. Such a perspective, conceptualizing the earth as a single, interconnected, living organism opens our minds to planetary consciousness. Such a supposition makes it impossible to ignore any longer that human enterprise must be considered within such a framework. Human activity must be integrated to have minimal impact on indigenous ecosystems yet be woven intimately into specific environments. The perceivable intricacies found within the microcosm of the cell teach us how living systems function. Their mechanisms have been developed through billions of years of evolution. An understanding of the processes of the cellular microcosm can be extrapolated to the study of the dynamics of the macrocosm of the biosphere and for this reason, the use of the cell as a model is appropriate.

> We shall not cease from exploration
> And the end of all our exploring
> Will be to arrive where we started
> And know the place for the first time.[4]

BIOENGINEERING & THE ORGANELLES

The mechanisms in cell biology applicable to the design of a human society are (1) the means of energy production, (2) transformation of energy to a widely applicable form, (3) the use of resources in productivity, and (4) the way in which productivity is managed and controlled. These are associated with different structures in the protoplasm of the cell.

The process by which the living cell incorporates these processes into means of internal productivity involves a complexity of networks in close biochemical communication. Within the cell, energy production and utilization, and protein production are in delicate balance and there is a direct relationship between chloroplasts, which are the organelles involved in photosynthesis, the mitochondria or subcellular components producing biochemical energy, and the ribosomes, which are the sites of protein production.

Essentially the chloroplasts are solar-driven factories within the plant cells. Through photosynthesis, the organelles produce sugars which are a primary energy source for other cell processes. The main compounds are water and carbon dioxide. Oxygen, as well as sugar, is a by-product of the reactions. Some of the oxygen is used by the cell in respiration. Excess quantities are released into the atmosphere. The excessive quantities of oxygen, in a sense, are waste products resulting from intensive productivity. Such efficiency and incorporation of all residual products, would be well worth emulating in industrial enterprises. The energy in the sugar produced by the chloroplasts is in a form that can be stored and used readily by the mitochondria.

The mitochondria function as generators of energy for biochemical reactions. They utilize the chemically bonded energy stored in the sugar molecules to produce ATP (adenosine triphosphate) from ADP (adenosine diphosphate), a compound that is a lower form of energy. This process is cyclic. ATP is readily accepted by almost all cell processes and provides the energy necessary for their operation. It is the task of the mitochondria to transform the energy in sugar into a mode useful for other biochemical processes within the cell. This activity of the organelle could be likened to that of an electricity generator. The chloroplast would be analogous to a windmill. Without its storage

[1] R. Dasmond, 1976, "Biogeographical Provinces," *The CoEvolution Quarterly*, 11 32–35.

[2] L. Thomas, 1974, *The Lives of the Cell* (New York: Viking Press).

[3] L. Margulis, and J. Lovelock, 1975, "The Atmosphere as Circulatory System of the Biosphere: The *Gaia* Hypothesis, *The CoEvolution Quarterly*, 6: 30–40.

[4] T. S. Eliot, *Four Quartets*, V

capacity, the sugar could be compared to the mechanical energy of a machine that can be used to drive a generator to produce electricity and to charge batteries, and is like the mitochondria in relation to the ADP to ATP reaction. The weakness in this analogy lies in the stages of energy storage, but the basic premise remains valid.

The respective sizes of the mitochondria and chloroplasts are nearly uniform. They are not contained in a single structure. Rather, the requirements that are answered by their processes are spread throughout the cytoplasm of the cells. Each cell contains different numbers of organelles, depending upon need. The entire cell is not dependent upon a single, large energy producing station. Both organelles contain their own genetic material and are capable of independent replication, dispersing the control of some processes throughout the cell, and leaving the responsibility for other activities to those entities directly involved in the particular process. Current ideas for decentralizing energy production are somewhat analogous to those of the cell and its micro-ecosystem.

This design permits a specific cellular reaction to take place at the site where it is required, reducing the need for extensive internal transport systems. Protein synthesis, for example, takes place throughout the cytoplasm, wherever there are ribosomes. Proteins are necessary for all structural and enzymatic activities. ATP is required for energy for their synthesis. The mitochondria found near a ribosome facilitates the supply of the energy compound. This is also the case for chloroplasts and mitochondria.

Proteins are made from a series of linked amino acids that can be used over and over again. Rather than repeat the energy-intensive process of synthesizing at every level in the food chain, biochemical means have evolved capable of breaking down proteins into individual amino-acid building blocks. For example, when one eats a carrot, the proteins in the carrot tissue cannot be used directly but, through the digestive process, are broken down into separate amino acids and then reassembled into useful proteins. Although extensive recycling of materials is a relatively novel concept in our society, it is an efficient process, well-tested in cell systems that are not involved in primary productivity.

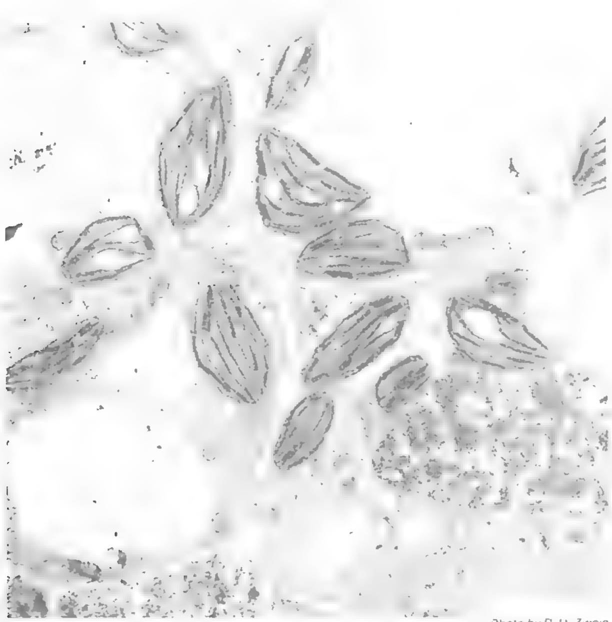


Photo by R. D. Zweig

MANAGEMENT AND BIOLOGICAL FEEDBACK

A last mechanism of the cell should be discussed before beginning an attempt to extrapolate to human settlements. There is, within cells, a tight management scheme for internal functions which are extensively governed through feedback pathways. It is known, for example, that the codes for protein synthesis are found in the cell nucleus. The nucleus secretes messages used by the ribosomex to produce a particular protein. It has been found that this sequence of events is controlled by the amount of protein available. A particular protein, in sufficient concentration, is capable of self-regulating the processes of its own synthesis. The effectiveness of this mechanism in any production scheme is obvious—the more direct the communication, the better the chances for healthy equilibrium or a viable economy.

APPLICATION OF CELL PRINCIPLES TO A HUMAN COMMUNITY

One way to approach ecological design is to look at existing engineered technologies. The chloroplast could be seen as offering an analogy that could be used to create more efficient sewage treatment plants that could convert wastes to usable products. At the present, there are facilities that have been designed and are in operation containing several of the stages of operation necessary to achieve such a goal. In such systems raw sewage is put first into primary treatment ponds where the solid material is converted to sludge through bacterial activity. Methane gas is generated through this anaerobic process in quantities sufficient for the mechanical operation of the sewage plant. Possibly excess heat from the process could be channeled into a district heating scheme, but this would depend upon the quantities available. The heat made available through this and other manufacturing processes could be utilized as a back-up for auxiliary passive solar architecture designs. As with cells, such an interconnected network is essential for the most efficient use of available resources.

The sludge can be converted to organic fertilizer for agriculture. The conversion process could be done using earthworms, and these in turn could be used in fish culture.[5] Perhaps the amount of sludge could be considered as an indicator of the amount of food necessary to sustain a community. If all food residues and human wastes were run through such systems, it should be possible to calculate the amount of food needed, providing a mechanism for direct feedback. Agriculture of a scale suitable to provide sufficient food could be designed to surround the settlement. Sludge fertilizer would be combined with compost from local plants and from inedible parts of harvested food plants.

Designs are being developed in the secondary stages of sewage purification that use algae in treating residual gray water. The algal cells can be removed through filtration and the water returned purified to the environment. The stability of such a system is obviously dependent on the quality of the sewage entering the plant and would have to be restricted to organic wastes free of heavy metals and toxic hydrocarbons. This remains a problem in most cities where municipal wastes enter a common sewer system. As is true with size of cells and organelles, the scale of a community remains an important consideration.

[5] J. Parkin, 1978, "Other Friends of the Earth," *The Journal of The New Alchemists, 5:* 69–72. P.O. Box 47, Woods Hole, MA 02543.

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Clearly, the above example is a simplified version of what will be necessary. What it does is offer a partial format for community designs that would be analogous to biological systems. It would be naive to assume that the model of a cell is a complete answer. The greatest strength of any biological system comes from the diversity of its components. Just as with the mixing of genes, inbreeding within a species gives rise to an increased potential for matching weak genes that could threaten the vitality of an individual and should, therefore, be avoided. It is best at this crossroads in design for human communities to combine the strongest components from a wide range of paradigms to create the most broadly applicable understanding. What has been true in the evolution of life itself should be true in evolving fundamental principles for community development. Synthesis with relevant ecological concepts provides the greatest chance for long-term stability in a society. Hopefully, the outcome will be a sensitive symbiosis.

Photo by Hilde Maingay

Near Horizon Economics and Renewable Resource Based Technologies

Joseph Seale

Modern industrialized countries virtually do not engage in any planning that extends beyond a decade ahead. In capitalist countries government planning is viewed with suspicion and fear of regulation and bureaucratization. It is discount rates, which represent competitive interest plus inflation and dictate the present value of anticipated future returns on invested capital, that substantially determine the time horizons of corporate planning. This sets those horizons very near in inflationary times.[1] Economic planning by individuals and families shapes the future only at the family level. The purchase of a house, for example, affects where and how one lives, or saving to send children to college affects their education and vocational future. But the way in which invested family money is used outside the family is seldom a family concern. Monetary abstractions of security, earnings, and growth rate obscure the particular impacts of investments on the direction of technological evolution. Capital return becomes the sole measure of investment value despite the multidimensional consequences of investments.

Before the industrial revolution, and to a lesser extent even up to the beginning of this century, there was considerable planning inherent in cultural tradi-

[1] For example, by geometric discounting (only one method), at a 25% annual rate (not uncommon for internal industry investments), next year's $1.00 earnings has a "present value" of $.80 (divide by 1.25), or $.64 two years hence (divide again by 1.25), then $.51, $.41 and $.33 for the $1.00 earned five years hence. Far-future anticipated returns, negative or positive, carry little weight in investment computations.

tions as the long-range consequences of certain activities were known by cultural experience. Planning did not depend on anticipating a future unlike any time in the past. But if cultural experience once bore some weight in decision making, modern forecasting seems useful, in practice, mainly to buttress self-righteous I-told-you-so's after a gloomy forecast comes true. It seems that now, as throughout history, people learn lessons the hard way as they are confronted by tangible consequences.

Increasingly tangible evidence is bringing many people to believe, however, that the future debts incurred by present types of industrial activity are rapidly overtaking us, and that, if our civilization is not to be swamped, our planning must begin to make allowance for debts bestowed on the future. The simple pollution-control measures of a few years ago are beginning to acquire dimensions of ecosystem management and future planning. Advocates are arguing for renewable resource based technologies to curb the depletion of and dependence on finite resources. They argue for an economy that future generations can carry forward.

Others contend that the strongest buffer against pollution and economic collapse is a strong industrial economy equipped with energy producing technologies that are equal to the tremendous energy costs of recycling materials and fighting pollution. Most of those of this persuasion consider that nuclear technologies alone can be implemented on a scale necessary for long-term needs, with pollution costs and hazards we can accept. Although many disagree with their assessment of nuclear pollution and hazards, few contest the warnings of nuclear proponents about the environmental costs of massive-scale coal-electric generation. Many people look to space for future resources. High-technology advocates argue that historically we have always been able to discover new resources, unimagined by our predecessors, as the need has arisen. They contend that the future can best take care of itself if we build a strong present, by which they mean not breaking the stride of a successful growth economy.

Both sides argue for national-scale priorities, although many renewable technology proponents favor that the priorities be accomplished not monolithically, but in ways that are appropriate regionally and by relatively small groups. This essay proposes that it is only as individuals and groups, in our economic and vocational activities, that we can effectively take responsibility for directing technology development according to long-range, whole-system value criteria. Such direction will not be accomplished by governmental edict that bureaucracies be funded to study large systems of the future, nor by legislation that industries follow the recommendations of experts or lobbies. We have a system in which individuals, and consequently the corporations they form, are encouraged to act entirely according to self-interest while the government is asked to determine what activities work to our collective detriment and to regulate economic activity accordingly. Yet regulation of one sector of the economy affects other sectors and other activities in ways that are as yet only poorly understood, and the impact of regulation is to generate confusion and waste.[2] The problem inherent in the free enterprise alternative, when self-interest degenerates into greed in the context of a corporate economy, is that anticompetitive activities can destroy the freedom of enterprise.

I have little confidence in either government regulation or in regulation entirely by "the market." If individuals are to intervene to the benefit of the whole system, which I believe is the only viable path, that intervention must arise from a basis broader than narrow self-interest. Intellectual tools, like an understanding of the downstream consequences of present choices, will only help. More critical is a sense of cultural continuity, an awareness of relationships to generations past as well as future, and an awareness of and reverence toward the interdependencies of all life in an ecosystem. While various traditional moral codes incorporate particular dimensions of ecosystem awareness, we, for a broadly ecological ethic, must look to a few long-lived primitive societies. Where we find such an ethic, it is not imposed by higher authority so much as it is integral to the prevailing concept of the self in relation to nature.[3] I should like to look at such cultural themes in relation to the theme of economic time horizons, and consider a few historical examples of changing time spans for investment planning.

In 1900, a young father might have invested his family capital and subsequently his labor, in land that he hoped to improve for the benefit of his new family and his grandchildren. His great-grandchildren would have lived beyond the time frame of his lifetime and his imagination.

In the Middle Ages, artisans labored to build cathedrals started before their birth and completed long after their death. Cathedrals were an investment to the glory of God on the part of the whole society to come full term with the Second Coming of Christ.

Before they made contact with Europeans, the Plains Indians of North America tried to live as to leave no trace of their life's passage on the land. Lasting value lay not in monuments, but in the uninterrupted cycles of nature. One's final investment toward maintaining natural cycles was one's body, whose decomposition

[2] See Gregory Bateson, "Conscious Purpose Versus Nature" and "Effects of Conscious Purpose on Human Adaptation," essays appearing in Part V of his *Steps to an Ecology of Mind* (Chandler Publishing Company). These essays apply not only to regulation of economic activity, but to human regulation of natural ecosystems, a topic of the remainder of this paper

[3] See Wendell Berry's essay, "A Secular Pilgrimage," from his collection, *A Continuous Harmony* (a Harvest book, Harcourt Brace Jovanovich).

would return the last of borrowed sustenance to the soil that gave life, although the word "investment" hardly fits here, for its modern usage implies the channeling of human effort or the currency of human effort, capital, to improve on the natural state of things. Currently investments are not based on the eternal cycles of nature.

Modern industrial equipment is amortized fully in about five years. Beyond that horizon, today's equipment is scrap. An example can be seen in the IRS schedules whereby companies depreciate capital equipment to salvage value in about five years. Computers give way to faster, more powerful computers. Typewriters give way to word processors. Fixed typewriter fonts yield to interchangeable fonts. Mechanical linotype fonts give way to evolving phototypesetting methods. Next come cathode ray tube (CRT) scanned optical fonts, then digital fonts that control CRT letter formation, and now digital fonts that steer laser beams to make offset plates in one step.

For a more detailed example of economic pressures leading to rapid technological advancement and equally rapid obsolescence, we should consider oil-well drilling technologies. Mud drilling, based on pipe rotation to turn rolling conical studded bits, mud flow to carry away cuttings, and drill stem weight for cutting force, is being challenged in dry continental formations by faster air drilling, which uses a flat studded bit face, compressed air to carry cuttings up the hole, and pressure differential between air and high internal pressure rock to eliminate the need for great mechanical cutting force.[4] Drilling with bits may be made obsolete in the future by fast erosion drilling, which uses very high pressure (up to 15,000 psi) drilling mud jets to cut through rock.[5]

Equipment becomes more specialized, complex, expensive, and far more productive—of necessity. To continue with the example of fast drilling technologies, large shallow continental fields run dry, forcing drillers to go deeper, or out to sea, for smaller returns in oil. Production demands drive companies from $4,000 per day shallow drilling in east Texas to $10,000 per day drilling in deeper, harder formations in the Rocky Mountains to $25,000 per day for shallow Gulf of Mexico drilling as high paying onshore reserves dwindle. From there, costs climb to $40,000 per day for U.S. East Coast offshore drilling, $40,000 to $60,000 per day for North Sea drilling, as waves, weather, and remoteness add their costs, and to $100,000 per day to drill through Arctic ice in northern Canada in search of even more difficult reserves. Completion times increase exponentially with depth, from a day or two in east Texas to four to six days for 8,000 ft. wells in southern Louisiana, to more than a year for 25,000 ft. mid-continent wells. Pressures for increased productivity, drilling speed in this case, come from the need to go to great depths, from high daily operating costs (crews, fuel, management), from interest on tied-up capital (drilling rigs, ships, offshore platforms and leases), from inflation, taxes, and ultimately from competing equipment manufacturers. These pressures force rapid technological evolution and correspondingly rapid obsolescence of equipment. Inflation is really having to spend more to get the same thing; however, some people claim that inflation can be cured by redirected government economic policy and ignore patterns like this. Do they think we can legislate easy-to-recover petroleum back into the ground?

On a deeper level, short horizon economics are a symptom of a race to stay in one place, to maintain our economy and our lifestyles even while nonrenewable resources vanish and must be replaced by resources that are harder to obtain, like offshore petroleum; or are currently more challenging to use, like solar energy (as contrasted with fuel oil), or depleted soils (as contrasted with the rich soils our ancestors used). The costs of environmental pollution and ecosystem damage have begun to acquire important economic proportions. We are racing to invent our way out of the consequences of past actions.

How do markets move from long to short range economics? Take agricultural land as an example. Land was once a very long-term investment, especially in Europe, where a tradition of conservative land management had evolved around centuries of use of a finite resource, which is an example of "planning" integrated with cultural tradition. Much of the investment was not so much in the land as acreage, as it was in the soils. Management included rotations of nitrogen-fixing legumes, soil-holding cover crops, and nonmarket "green manure" crops to be turned under for soil fertility. Animal husbandry and market farming were complementary, as manure was a necessary part of agriculture. The land produced "fuel" for draft animals, and the animals returned fertilizer.

With the settling of America, people discovered that they could use land more easily as a nonrenewable resource and neglected conservation practices. Depleted soils could be abandoned for land further west which led eventually to the geographic separation of farms and markets, a pattern that now locks us into costly long-range transport of food. Later with chemical fertilizers, farmers found a technological fix for the accumulating consequences of their nonconserving practices. The tremendous success of fertilizers led farmers to ignore tradition altogether. Increasing mechanization encouraged larger field size. Mechanization, economic pressure, and loss of a cultural

4 Mile-deep rock is under extreme pressure of rock weighing down from above. In air drilling, this internal pressure causes rock to break loose easily into the much lower pressure air environment. The drill bit does comparatively little work.

5 Roy Long, Jr., Tenneco Oil Co., provided most of the specifics for the above paragraph.

memory that trees are useful in agriculture led to the cutting of windbreaks. Consequently, wind-caused crop damage and erosion increased. Birds would not venture out across large fields, far from protective cover, to feed on agricultural pests. And the simplified soil ecosystems bred of chemical fertilization and pest management did not support the biological balances that once held many pests in check. Selective evolutionary pressures from pesticides caused fast-evolving insects to develop resistance while bird populations that evolve more slowly dwindled, enforcing the escalation of the pesticide war. Further destruction of soil microbial ecosystems reduced the pathways by which soil minerals were converted to compounds available for uptake by roots, while breeding for optimal productivity with fertilization led to dwarfed root systems equipped to feed only on soluble fertilizers.

In modern practice, "soil" is used in the singular, for its use is largely undifferentiated. Soil is space for plants to grow in sunlight. Soil is a floor to bear the passage of plant-tending machinery. Soil is a mechanical structure stable enough to hold plants upright by their miniaturized root systems. Soil is capillary structure to hold the nutrient chemical solutions on which roots feed and the vermiculite of the most economical form of mass hydroponic food production. Soil fertility has moved from an investment lasting for generations to a one-season investment: chemicals on, crops off. Land under this type of management acquires a time horizon for agricultural use of decades, not centuries.

Current economies rely largely on resources that are either nonrenewable and in short supply or else in imminent danger of depletion faster than can be resupplied by nature. It seems relevant to ask which forms of resource depletion are most likely to affect the race to invent our way out of past consequences.

Fossil fuels, particularly petroleum, are becoming harder to recover as prime reserves vanish. Long before supplies are gone, several rising costs will combine to outweigh the value of these resources as fuel. These include the rising recovery and extraction costs mentioned earlier, as in offshore petroleum, oil shales, tar sands, land reclamation costs in relation to strip-mined coal and oil shales, and the costs of pollution control for substances like high-sulfur coal and petroleum. The uses of fossil resources in chemicals and materials are likely to outlast fuel uses, but at a price.

Metals are becoming harder to recover. In cases like aluminum, ores are abundant, but the tremendous energy requirements for electrolytic refining binds the costs of aluminum to energy costs. In other cases, supplies of good ores will be more limiting, and metal recovery from poorer ores costs much more in labor, equipment, and energy. These rising costs pose a threat to the construction of many of the devices supposed to form the basis of renewable resource technologies.

Soils are being depleted in two ways. Erosion has already claimed about one-third of American topsoils, and loss is accelerating despite $15 billion spent since the 1930's to fight erosion. The destruction of soil structure, organic matter, and microbial ecosystems is reversible in principle, but only over decades, and at considerable expense. This soil destruction enforces the continuation of the agricultural methods that brought it on, while the quality of soil, even as a hydroponic medium, deteriorates with the on-going loss of organic matter. Microbial ecosystems are essential both for the conversion of soil minerals to compounds useful to plants and in the return of potentially recyclable components removed with the harvested crop.

Water resources are coming to be used to capacity. In agriculture, destruction of soil structure reduces water retention, increasing both the demand for irrigation and rainwater runoff, accelerating erosion, and creating expensive flood-control problems. It is easy to forget that the kind of damaging floods we commonly experience or read about were rare in North America 200 years ago. Industrial uses of water, such as pumping water-suspensions of crushed coal from mines to generating plants, threaten to lower water table and disrupt ecosystems, ultimately destroying soils and species.

Mineral phosphate reserves are declining rapidly. This is tied again to unsustainable soil management, which fails to recycle phosphrus-bearing manures, sewage, and garbage, and allows the leaching of phosphorus from poor soil structure.

The genetic stocks of the biosphere are being destroyed, as the last areas of arable land are brought under tillage. Modern agriculture has relied on the infusion of diversity from wild genetic plant-stocks to develop new domesticated breeds that combine good productivity under specific growth environments with pest and disease resistance. But the green revolution led to the development of plants optimized for petro-chemical-based agriculture. The decline of fossil fuel resources will generate needs for very different crops and these cannot be developed without genetic raw materials.

It is currently common to call the depletion of such resources an "energy crisis." While energy is indeed very important to an industrialized economy and to industrialized agriculture, the term "energy crisis" seems frighteningly narrow, as the issues raised above should suggest. And the measures that are proposed to fight the "energy crisis, with vast energy-producing technologies, are still more frightening for the capital and the intelligent thinking that such projects would divert from whole-system problems and

from the underlying roots of the symptomatic energy shortages. Increasing numbers of people are advocating efforts toward breeder fission and hydrogen fusion technologies that would require commitment of a large fraction of the national GNP. While the costs of dealing with the side effects of nuclear power cannot be argued concretely, as they are unknown, and the necessary technologies do not exist, the fact that the costs of dismantling the first spent reactors had exceeded their huge construction costs warns of future economic debts on an unprecedented scale. Unfortunately, some proposals for renewable-resource-based technologies, particularly those focused single-mindedly on the production of energy outside contexts of use, sound equally inadequate, if a little more benign. Two examples will illustrate.

Many engineers propose planting monocrop stands of fast-growing fuel trees, clear cutting and replanting every two to four years. Whole trees would be removed and burned in electric generating plants. Could such practice result in net profit and sustainable yields, or would it use forest soils as nonrenewable resources? Agricultural experience by now should indicate the high energy costs of maintaining stable immature monocrop ecosystems against a biosphere that attempts to reimpose diversity. Pests are certain to require constant control. Regular irrigation, fertilization and herbicide control are anticipated as though there would be plenty of water for this new and massive need, and as though the energetics of fertilizer and herbicide manufacture without petrochemicals would permit such practices.

What would be taken from soil? Nitrogen. Phosphorus. Potassium. Carbon, which is organic matter from decay. Minerals. Short-horizon agriculture recognizes the first three elements primarily. The nitrogen compounds in wood would generate volatile, polluting stack effluents. Would such compounds be scrubbed from stack gases and processed to a form more suitable for fertilization? Or would it be cheaper to dispose of scrubbed effluents and synthesize fertilizer from atmospheric nitrogen? Power-plant ash would contain phosphorus, potassium, and trace minerals that hopefully could easily be returned to soils. What of carbon? Fuel woods would be hardwoods, whose leaves are better soil builders than needles. Is that sufficient? Or will the soil structure deteriorate?

Natural forests, and some managed European forests as well, contain decaying trees that provide food for bacteria, fungi, insects, and ultimately birds and small mammals. Varieties of seeds from different tree species feed birds and animals, thereby creating niches for larger predators. The droppings and decaying bodies of the insect, animal and bird life sheltered by a forest provide soil-building inputs beyond the mere chemical elements necessary. Enduring soil ecosystems which maintain structure and microbe-driven nutrient cycles have evolved with these inputs. Pests are a result of predator-prey imbalances that seldom occur in forests with mature trees, species diversity and the accompanying diversity of animals, birds, and insects.

Forest managers try to maintain early succession ecosystems that are more productive than climax forests. In nature, less mature forests are more diverse than slow-moving climax forests. To push for both extreme immaturity and uniformity implies difficult, energy-intensive management. It seems doubtful that many current biofuel forest plans would fundamentally have a more renewable basis—in fact, coal would probably be a much longer-lasting resource than unwisely exploited forests.[7]

Can windmills become part of a sustainable economy? Once, wind machines were used to accomplish mechanical tasks directly, primarily those of grain milling and water pumping. The products of these tasks, flours and pumped water, could be stored for the duration of calm spells. Now that energy production and task performance have evolved into separate specialties, windmills are being designed almost exclusively to produce one of the prime commodities of energy exchange, electricity. For that single purpose, windmills are being made more efficiently year by year in the manner of industrial products in general. But, unlike grain milling or water pumping, the task of electricity generation alone is incomplete and requires an array of other devices to serve human needs. Electrical systems cost enormous amounts of capital, energy, and materials to build.[8] For wind-generated electricity systems of the near future, fossil fuels are likely to provide much of the back-up power for periods of inadequate wind. But once the chemical energy stored in fossil fuels is depleted, as when the energy costs of recovery exceed the energy value of the fuels, then the high costs of other forms of electrical energy storage and back-up power will further diminish the net absolute worth of wind-powered electricity generators.

This is not an argument against the relative merits of the wind-generation of electricity, which look quite

[7] For a more hopeful view of what can be accomplished through sound agricultural and forestry management, see Earle Barnhart, "On the Feasibility of a Permanent Agricultural Landscape" in *The Journal of The New Alchemists # 5*. While Barnhart's paper indicates constructive approaches for dealing with many of the specters raised here, the paper makes it clear that implementation of these approaches can happen only in a context of long-range economic planning.

[8] See Amory Lovins, *Soft Energy Paths: Toward A Durable Peace* (Friends of the Earth and Ballinger Publishing Co.) for broad-ranging research into these costs and their implications. For a briefer view of some of the solar technology implications of electrical system costs, plus concepts on systems integration, see Joe Seale, "Sun, Wind, and the Power Company," *CoEvolution Quarterly*, Winter 1978 79 issue. For an end-use oriented, integrated wind system description, see Joe Seale, "An Integrated Wind-Powered System to Pump, Store, and Deliver Heat and Cold" in this issue of *The Journal of The New Alchemists*.

Photo by Hilde Maingay

favorable. For certain premium uses where continuous energy in electrical form is indispensable, or where power can be intermittent with the wind, wind-generated electricity is likely to rank with the best energy resources. The question of net absolute worth is as follows: Will the costs of future total wind energy systems for continuous power approach or exceed the value of their lifetime energy production? If the costs are too high, then such systems would require a net subsidy, even though they might be constructed for their special utility in limited applications. This caveat applies to other renewable resource technologies. Only the best-conceived renewable-resource-based economy, as a well-integrated assembly of component technologies, is likely to be self-sustaining. The "out" of continuing much longer to discover new nonrenewable resources to exploit seems less promising. Only clear systematic thinking and planning will sustain us.

As I said earlier, the problems we face are much too broad to be termed an "energy crisis." Gregory Bateson reminds us that what is called "human energy," and especially "psychic energy," seldom means the kind of energy defined by Newtonian and Einsteinian physics, and would better be termed information, control, or intelligence.[9] That a light bulb and a computer consume equal wattages says nothing of their comparative "computing power." The "energy" crisis might more properly be called an information crisis, a failure of intelligent control of our technology. The examples from agriculture and forest management should indicate the ways in which ignorance of how ecosystems can help us achieve human ends has led to prodigious expenditures of real energy, the kind measured in Btu's or horsepower hours or kilowatt hours. Eugene P. Odum made a statement about plant "energy" and human "energy," meaning energy plus information or organization: "A lot of energy (human or otherwise) other than fuel is required to keep machines running, repaired, and replaced; it is not fair to compare engines and biological systems unless this is considered, because the latter are self-repairing and self-perpetuating."[10] The folk adage is, "Things break down." Whereas broken-down machines are scrap requiring energy for disposal or recycling, dead plants and animals in a healthy ecosystem provide both nutrients and food energy to the microbes that carry their material back into the cycles of plant and animal life.

American Indians were the last residents of this land to participate fully in such cycles. Can our society find ways to build sustainable technologies with intelligence, especially biological intelligence, where brute energy has failed us? Beginnings of positive answers

[9] Gregory Bateson, 'Form, Substance and Difference," op. cit. After reading this and the two essays mentioned previously, the reader may well be inspired to tackle the whole book of essays, which is wonderfully wise and coherent.

[10] Eugene P. Odum, *Fundamentals of Ecology*, W. B. Saunders Co., p. 77

lie all around us. Solar greenhouses that avoid the costs of heating fuel and produce vegetables in the area where they are consumed cut into the cost and resource depletion of long-range food shipment. Bioshelters combining greenhouse agriculture with aquaculture make double use of water for thermal storage and fish raising, use algae and bacteria to purify the water and help feed the fish, use fish wastes to fertilize plants, and use compost heat and CO_2 to enhance plant productivity before the finished compost builds soil fertility and vitality.[11] A waste-water treatment facility that was half as expensive to build as its chemical-based counterparts uses sunlight, rather than fossil or nuclear-derived energy, and plants for energy conversion to purify water.[12] Some of the plants promise to become useful as cattle feed. A large mixed farm in Iowa operated according to biological principles has slightly lower productivity per acre than neighboring farms using chemicals but it operates in the black, because of reduced operating costs, whereas neighboring farms are owned by the banks.[13]

Another issue of trade-off between energy and intelligence involves the conflict between corporate structure and the efficient integration of systems. Industry is geared toward the manufacture of modules and will, for reasons of profit, promote the sale of complete modular systems over the sale of materials that require finishing outside industry. On the marketing side, advertising is effective at selling modules, not concepts. The best practical example of this is solar space-heating systems. Industries have developed and promoted modular component systems consisting of solar collectors, heat-storage reservoirs, heat exchangers, blowers and/or pumps, and controls. These modules taken together are a direct physical and conceptual replacement for a furnace heating system. The concept being sold is simple: "The fuel for this furnace is free." This sort of marketing molds popular opinion, even though high costs prevent large sales. How many places do we see slogans like "Plug into the Sun and Wind!" or "Switch to Solar Energy!" as if simple substitution of one form of energy for another, all in the same unintegrated framework, would cure our ills? Now that solar space-heating has been identified in the popular consciousness with active solar-collector systems, intelligently edited magazines and journals carry the post-mortems: " . . . uneconomical . . ."; " . . . unfulfilled promise . . . "; " . . . complex and unreliable . . . "; " . . . too costly for the homeowner. . . ."

Meanwhile, a new tradition of integrated solar architecture based on the initiative of many individuals and not supported by mass marketing is gaining a foothold. Glass walls with insulating shades are more expensive than insulated walls, but far less expensive than insulated walls plus solar collectors plus thermal transport mechanisms. Designed-in masonry or water containers exposed directly to sunlight are more cost-effective storage media than rock storage piles with blowers and ducts, or than water tanks with pumps and blowers and heat exchangers and ducts. Granted, the more passive integrated solar approaches offer less tight temperature control, but that is a trade-off that increasing numbers of homeowners are willing to accept for reasons of economy and security. Homeowners are also reluctant to become dependent on repair specialists to keep complex plumbing, motors, pumps, and controls operating. The "energy crisis" lies in hundreds of thousands of badly constructed, leaky, large (oversize by my prejudices) houses going up each year, where well-constructed, integrated solar houses would not create such large new energy demands.

To call consumers the victims of industry in situations like this is to point to the counterproductive but mutually reinforcing habits of industries and consumers. It takes two parties to make a mental illness. The two parties here are the warring factions of the body politic, our divided selves.[14] As consumers, we are victims. But as consumers making purchases, we control part of the capital flow of the economy. If we invest, our investment choices reinforce or discourage corporate patterns. If we are blind to all but maximum investment returns, we reinforce the short economic horizons that are a formidable barrier to long-range renewable technology investments. To be employees of a system we may wish to change, or to be in a vocation that does not help shape a future we would choose, is perhaps unavoidable in the short run. But eventually there is always other work to move into by our own choice, if we make it. Economic inducements usually discourage vocational innovation. High-school and college career-placement counselors too often play the role of market analysts, using computer-based job market forecasts to suggest where we (or our children) might best cast our abilities, how we might most profitably sell ourselves in the market place. At colleges, the Future wears a business suit and visits campuses near the time of graduation, illustrating how Still the Future can choose us with the apparent inevitability of Progress.

Or we can choose the future.

[11] "From Our Experience," Part 5, see p. 146.

[12] Frank Balyn, "Solar Sewage Treatment," *Popular Science* May, 1979, pp. 106-7.

[13] Richard and Sharon Thompson operate 420 acres; they specialize in corn and cattle raising. For an account, send for: Proceedings of the First Conference on Biological Agriculture, Spring 1978. Charlottetown, P.E.I., Canada. Send $7.00 to Martha Musgrove, Institute of Man and Resources, 50 Water St., Charlottetown, Prince Edward Island, Canada.

[14] Wendell Berry offers a fine exposition of this concept in *The Unsettling of America: Culture and Agriculture* (Sierra Club Books; published by Avon Books), especially in chapter 2. He contrasts the integrating effects of traditional agriculture as nurturing stewardship with the fragmenting effects of exploitive industry and industrialized agriculture. Though Mr. Berry's emphases are cultural and agricultural, his thought has been a cornerstone for these arguments focused on economics and technology development.

From a painting by Sava Morgan

Learning and Unlearning: Some Patterns and Connections

Jeffrey Parkin and Sava Morgan

The interview that follows arose from a strong feeling, one that I share with many other people, that Sava Morgan's approach to painting and to teaching, which amounts essentially to learning from one's self and from others, should be shared. I first met Sava when I became a participant in her painting workshops. The beauty of her classes is that they are meant for everyone not just for artists per se. Through our painting, she prompted each of us to take a hard look at ourselves. In many instances, this was quite a revelation.

In my case, much of my pre-college life was devoted to formal training in art, then my college days were spent predominantly in science. For many years, I thought of my art and my science as complementing one another, the subjective and the objective, the yin and the yang. Throughout my first twelve years of school, I was taught in art to render my reality objectively. While this is perhaps a logical, initial step for aspiring artists, most of us, particularly when we are very young, are not aspiring artists. Yet largely without exception, elementary-school children are encouraged to compose the inevitable witches on broomsticks at Halloween, predictable turkeys and Pilgrims at Thanksgiving, assembly-line Santa Clauses and evergreens at Christmas, and so on as the years and children go on. Our perception of reality thus, as objective, through various forms of art, is not fundamentally different from science. With my background, I found it difficult in Sava's classes to displace my objectivity for long enough to find a greater balance within myself. It is the rare teacher outside the discipline of Zen Buddhism who asks questions without answers, offering art as a vehicle for self-expression and self-awareness, as a true complement to science.

Sava is such a teacher. Although she defies translation onto paper, I have not been able to resist the impulse to try.

Jeff: What do you think are the most important aspects of your teaching of painting?

Sava: Many modern artists, like Dubuffet, Klee, and Picasso, studied young children's art in the hope of capturing some of its spontaneity. I wondered if it was possible to trigger comparably spontaneous activity in adults. In my adult art classes, I attempt to have participants relate individually to experiences still within them, from their pre-school stage (from about two to six years of age). The period is often referred to as the mytho-poetic or what Piaget termed the preoperational stage of childhood. It is a time in people's lives when they can directly express their perceptions of reality through movement, feelings, color, music and through metaphor, without intellectualizing or being bothered about the final product or outcome. In our workshops, we play. We experiment with materials like large brushes, primary poster paints and inexpensive paper, as children do. You express yourself with individual spontaneity, through color and forms. As part of the process, you feel the extent to which you want the colors to flow, to combine to new hues, to fill spaces, and so on.

Working like this you might move into a new phase. When presented with the exploration of materials exclusively, you focus on constructing configurations in relation to the paper and to your perceptions. These configurations may be developed into a world of your own—figurative, associative, or abstract. The application of paint may be lacy, heavy or patterned. When painting a plant, I may suggest that you imagine how it would feel if it were made out of bricks or feathers. By doing so, you could communicate many of the qualities inherent in nature—the hardness of a trunk, the softness of a leaf. Often, you may not understand what you are doing, but connections evolve out of enjoying the work rather than aiming at results. You reach toward your own understanding and expression rather than making something that is going to be pleasing to others. You become childlike in that you are searching. A joy like that in dancing, jumping, or playing is experienced in your painting.

An important element in realizing this lies in discarding tools usually employed for achieveing perfection. The pencil, pen or fine brush in the child or adult hand is directed toward achieving results acceptable to other people. You must be able to write legibly and draw clear, straight lines, or a smooth circle. Throughout all these years, you are conditioned to direct your hands toward planned, nonspontaneous activity. Attempting to achieve this, you have inhibited other parts of your self-expression, fragmenting yourself. If you did not enjoy your work, you relinquished pleasure for approval.

Photo by Hilde Maingay

Using large brushes and primary colors, you are reintroduced to attributes of nature like color, space and movement, as detached from a particular object. This is characteristic of tribal art, which is an integrated communication of total experience in symbolic form, through construction rather than imitation. The quality of essential communication about a state of mind connects the art of tribal people with that of children. In tribal art, utility and spiritual values were one. A drinking vessel can have both ceremonial and symbolic meaning. The work of the artist has spiritual significance, rooted in the collective life of the tribe. In my classes, you approach attributes of nature from your own subconscious and preconscious experience in an analogous way. You begin to perceive and treat these interconnected attributes as flowing through you. You are not by-passing your subconscious to fabricate a product that might be admired. I try to help you take away the striving for perfection, so that you can begin to confront your basic, creative imperfection. This may lead you toward new concepts and discoveries.

This is why I emphasize change when we work. Each time you do something to your satisfaction, I encourage you to do something entirely different in which you will have to use other capacities. This will lead to balancing achievement in one direction with other aspects of exploration. My hope is that you begin to enjoy every aspect of yourself, which will gradually result in an improvement of skills through

the process of self-evaluation in terms of your own complexity. The hope is for a person with an awareness of self rather than one who has been programmed to achieve a standardized performance.

If you ask me, "is my painting good?," I turn it back to you and ask, in the manner of Carl Rogers, "Does it please you? Is the feeling good? Did you discover something?" You achieve control of your own activities in terms of your demands on yourself.

In broader terms, the type of education I envision has many of its roots in the procedure of Fritz Perls. I try deliberately to disturb you by confronting you with your stereotype. Through your paintings, or whatever form of expression you have used, I show you that often you do not speak for your real self: you have been stuck for many years in a certain manner of working because that is what you were taught. Like one of Perls' clients, you may use a greeting to avoid rather than make contact with people. Then when you realize this aspect of yourself, you wonder what to do. I may encourage you to try working with color, to use it in a new way, to perceive it as overlapping spaces, to stop making outlines, to confront that painting as you would a new person. And that new person is yourself. Because you are unfamiliar with this, you may implode and then explode your negative feelings about this confrontation. Yet, as you begin to conceive of a new aspect of yourself, I try to help you to view it and express it. But I do this only when you have developed criteria that are valid for you, not only for me. This is why, when I teach painting, I encourage people to discover things important in their own lives that become valid artistically, and then make a statement of strong conviction. Originally, the intent is not to make statements to others. It is to explore the process of your own growth, your own capacities, and your own satisfaction.

Jeff: Why do you think painting is uniquely suited for the self-exploration and expression you speak of?

Sava: When you dance or play music, it escapes from you minute by minute. Photography and film tend to be technical expressions of selection and association suspended in time. Construction into single frames mediated by an instrument can remain a process of fragmentation. The moment you read back writing, it becomes linear; words and sentences ordinarily follow one another according to grammatical sequence and are viewed analytically. Even sculpture can be viewed from a linear point of view, as you walk around it. You may see it one part after another. In painting, the image is flat and confronts you as a whole.

While you are painting, you may, within your painting, have a mirror of yourself, moment to moment. You can see what you felt because unlike music the temporal dimension is hidden. Through painting you can sense your own control over the space as it occurs in time. This is important. According to Cassirer, the spatial concept came before the temporal. In the templum, which was space, one could contemplate, and thus tempus, time, arose. So you go from space, to considering space in time, to the origin of the concept of time. Painting illustrates this process.

Jeff: Having taught in elementary school and colleges, how do you view the current educational process?

Sava: Much of education today is based on the cumulative theories of the behaviorists, particularly those of Skinner. By eliminating the dimensions and complexities that are part of children's personalities, they can be treated as "black boxes," repositories for facts and programs. Then it is justifiable to reinforce those qualities important for optimal operation as a cog in the wheel of our progressive social machine. Education is analogous to feeding. The child may consume what is offered by way of education, and may even find it palatable. Because of the great pliability of the young child, this is overtly successful in the short term.

New curricula are devised to increase the level of performance rather than competence. The flaw in this lies in the fact, as Chomsky states, "that production is a small fraction of competence" at every stage of growth and development. Not only is the fraction an inconsistent, inaccurate tool for evaluation, but encouraging performance (production) has an effect that at best is indirect in revealing competence. Actually, stressing performance in education has led to an increased level of incompetence in many students because of rebellion inherent in many living organisms against being cast into molds not their own. It is useless to attempt to change an eagle into a duck.

The product orientation of education is comparable to our approach to agriculture. Crop yields are increased through the application of synthetic fertilizers A direct relation between the input of fertilizer and the output, or performance, of crops can be measured, and serves as the basis for evaluation. The natural balance or needs of the environment are not considered. As we judge a crop by one standard, that of yield, we assess children by two: How much of the input of programmed information is processed and at what rate? Real understanding is disregarded. If either, and certainly if both, of the two outputs fall below a certain standard of achievement, the children are pronounced failures by their educators and then by themselves. Such so-called failures arise because the children do not accept the inputs they are given as relating to themselves. The particularities of their growth and expression are not nurtured. In fact, our de-emphasis and, in many cases, ignorance of the processes leading to fruition, whether in an individual or a crop, has resulted in the long-term despoiling of two of our most precious resources.

Jeff: Returning momentarily to the "education" you give in your art class, I was fascinated by your observa-

tions on early childhood. What do you feel are the important aspects of the mytho-poetic stage of childhood and what might we learn from it as adults?

Sava: The ability to view each experience in a unified sense is one of the most important aspects of the mytho-poetic stage of childhood. It is in this stage that children still perceive a story as a story, a holistic image, not as a series of paragraphs, sentences, dictionary words or letters. Reading stories in order to learn words and grammar and to spell removes the children from the content and meaning of the story. In promoting forms of linear thinking, such as spelling or counting, among children of this age, we destroy their potential for unifying each experience through their own connections. It is hardly surprising that many children reject their teacher's attempts at injections of skills that are devoid of connections with themselves. In our haste to groom children for adulthood, we deprive them of a rich inner life at a time when it is ripe for development. We promote stereotypes. I don't deny that historically linear thinking has been and is of tremendous importance, but I do think that the skills can be taught too early in children's lives.

In the mytho-poetic stage, the integration of one process with another occurs not through logical analogy but through artistic metaphor. Children may project the emotions they feel at a given moment on an animal or object; they identify their experiences with an external world. Their realities are composed of passing series of experiences and feelings related, connected, to them. This is how they perceive their world as unified. If I understand morality as an interdependence of the entire world, then the mytho-poetic stage forms a basis of feeling for ethics.

I have seen a little girl of four walk up to a fire hydrant, clutch the two arms and say, "How are you, my little teddy bear? It is so nice to meet you." Children see the events of the world as things connected to their own lives; they befriend objects as animals. Each event, each animal, and object has a special significance in terms of a child's needs, not unlike tribal people who create gods that correlate significances in their lives. Tribal hunters and gatherers represented plants, animals and natural phenomenon through language, religion and myth, seeing in them innumerable connections and meanings. In tribal culture as in childhood, a person lives in a world of significance and connections. Though some of their perceptions might not appear objectively valid to us, it is important to keep in mind that they were and are valid to their holistic worlds.

The relating of object and significance is exemplified in children's paintings. In depicting her mother and father seated at a table, one child greatly exaggerated the size of her parents relative to the table, signifying comparative importance. My grandson has portrayed his mother as a lady with two (he has a little brother) small birds on her shoulder, the significance being in the large, nourishing, goddess mother and the two little birds whom she feeds. This is a reccurring metaphor in children's paintings and drawings.

Cassirer said that creating connections between objects is more important to humanity than formulating the classes to which the objects belong. As I mentioned earlier, it is these relations between objects and events as they change from moment to moment that form the basis of tribal psychology. This concept can be found in the immersion in the here-and-now in Chinese philosophy and in nomadic cultures. People constantly on the move, rooted in impermanence, must be aware of the here-and-now. Similarly, when children, absorbed in the moment, are asked what they were doing a little while ago, they don't remember. They are so completely involved in the present task, the here-and-now. Events as experienced by children are structured in the mind as a series of sporadic occurrences, not as a continuum. This may have a physiological basis in the growth of the brain cells.

Jeff: Schumacher considered education "the greatest resource." For the potential of this resource to be realized, it's obvious that the role of the teacher is of utmost importance. In the classroom, what do you consider to be the most important functions of the teacher?

Sava: The period when children have the greatest potential for perceiving wholes as well as essential qualities occurs in the mytho-poetic stage. This is well-documented in the literature of developmental psychology. With traditional education children learn spelling, grammar and other formal aspects of communication rather than content through which they can identify and experience. Children are trained to judge by formal qualities rather than to relate the instruction as applying to themselves. Gradually the ability to distinguish between the essential and the irrelevant in order to function optimally in balance with the environment becomes clouded. Such a shift in perception can eventually result in people who vote for a candidate on the basis of appearance, or buy a chair because of the veneer. More serious is the justification of prejudice and war which can be the consequences of bonding emotional states with theories, as we saw in Nazi racism and social Darwinism.

This is an example of how this might occur. Walking through a zoo with a child, an adult may say, "ick. . . that hippopotamus is disgusting; look at how he wallows in the mud!" Such a judgment is both directed toward the animal and child. How can anything dirty be beautiful? And the hippo is dismissed. With children it is most important that you examine the beauty of a particular structure within its own environment, separating subjective responses from objective qualities. Through my teaching, I attempt to help people of any age to discriminate between what is essential to them and to their work and what is peripheral, between what is true and what is merely pretty.

Photo by R. D. Zweig

This process has a wide and much-needed application in education. This might well be adapted to the method often used in teaching numbers. Children frequently are presented with three horses, five chickens, six houses, seven spoons, and the like, from which they are supposed to learn the abstract concept of number. It becomes easy for the child to fuse or confuse horsiness, or whatever, with the quality of numbers. Rather than eliciting the abstract understanding of number, the teacher achieves a fixation on those qualities. This is how people can come to attribute qualities to a concept or an object that have little or nothing to do with it, being unable, many times, to distinguish between what is inherent and essential to it and what is not. Suppose instead the children were exposed to four sets of the same number of objects, all of which were different. Eliminating color, the qualities of the animals and all concrete qualities at which children in this particular developmental stage are so apt, they would arrive through the process of reasoning at the abstract quality of number. The concept thus becomes general rather than qualified by irrelevant data.

Jeff: It seems to me that an important aspect of the teacher-student relation (or maybe any relation for that matter) is the difference between approval and acceptance. What do you think about this?

Sava: Very few instances arise in any classroom in which approval can be given with a long-term positive outcome. In most cases it has the effect of stunting. The only time I tend to show approval is when someone lacks a self-image with which to promote themselves or their work—when they are floundering. I give approval immediately followed by acceptance of that person. In essence I am saying "It is good that you have lost your way. This is evidence of your searching. The world is indeed complicated and it is something we all struggle with at one time or another."

On the other hand, the bestowing of approval upon a child or adult can be viewed as condescension. When people have low self-images, they may feel that you are flattering them rather than respecting them or valuing their intellectual capacities. Also approval can isolate a child from other children by making the others feel rejected. The self-analysis, or self-admiration resulting, distracts the children. When someone is given a grade or a distinction of whatever sort, the process of learning may actually be arrested.

This comes back to the bonding of irrelevant qualities to concepts, events or objects. The children's distinctions between their own processes of learning, or their subjective feelings of growth, and the objective grading of their performances by the teacher become obscured. As educators impose and reinforce these irrelevant connections, students often turn to bask in an artificial sun that gives warmth but no illumination.

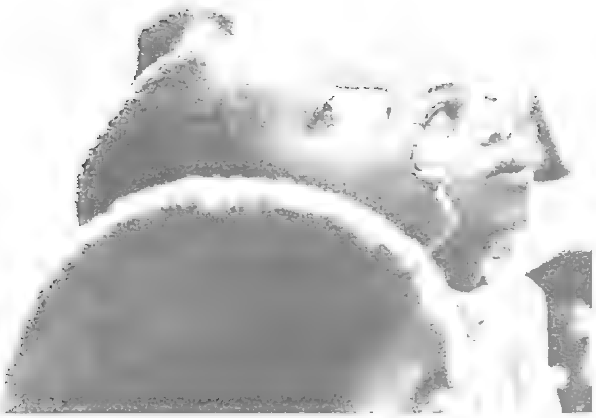
Approval stratifies you as good, mediocre and/or bad; acceptance means I am interested in you and what you are doing. Whereas approval serves to assert the authority of the teacher, acceptance denotes an egalitarian situation within the classroom as a whole. Acceptance offers internal support for the person's growth and expression, rather than a crutch. Often in class, something may happen outside the window that diverts the attention of the children, perhaps the flight of an interesting bird. The excitement awakened by this event could be channeled creatively. They could express the ways in which they experienced it into a drawing, a musical composition, a drama, a written story, or in any combination of these. The crux is the acceptance of an event which has come into the children's world, of the children and their excitement into the entirety of the learning situation.

Jeff: What is your approach to integrating withdrawn and disruptive children into the learning situation?

Sava: Withdrawn children are often responding to damage that has been done to them by refusing to face the world. Frequently, they don't want to participate in classroom activities and hesitate to talk. Their activities can be just as disruptive to the class as those of hyperkinetic children. I once had a little girl in one of my classes who was seeking the teacher's attention and affection constantly. She was given a box of bandaids and asked if she would take care of the other children's hurts. Gradually her desperate need to be loved was extended outward to helping others as well. Instead of pestering and clinging to the teacher, she became aware of the other children. Whenever someone cut themselves, she was there in a flash with her box of bandaids. Realizing that her actions were of value to others increased her self-esteem. Her need for a special bond with an "important person" began to disappear and she began to take on activities in which she acted on her own. It was through this special function that she became accepted by her classmates and was able to receive acceptance not only from them, but also from the teacher and ultimately from herself. While withdrawn children need approval even while they can't welcome it, acceptance can be the dynamic, growing approval needed for healthy relations.

Disruptive children tend to respond to the way that they have been hurt by acting it out. The child I have just told you about came from a family of ten in which she had no chance to express herself or to receive any individual recognition. In other cases, the disruptiveness of the action can depend upon what is required to elicit a response. When children are confronted daily with the difficulties of a ghetto, this is complicated and accentuated to an extreme.

When I was a teacher at Public School 113 in Harlem, I was given a small group of fourth-grade students that the other teachers couldn't manage because of their disruptive tendencies. I disapproved of or



punished these children very infrequently, but rather I tried to create for them a special situation that would utilize the intensity of their energy. I might say something like, "Let's try something new; what would you like to do?" Usually they would have no answer; then I might suggest, "Let's get some instruments and play a rainy-day tune. Let's listen to the drops fall and each one of you make the sounds in your own way. Find your own beat. Just put the sounds together so that you enjoy listening to them, and then play with them." They played for awhile, then went off, with my encouragement, to the kindergarten, first and second grade classes to explain to their little brothers and sisters about improvised music.

I tried to do some reading with them. At that point, although they were in the fourth grade, none of them were able to read. They were uninspired to do so, and had a strong aversion to books, particularly ones they felt were for younger children. Here I said, "You want your little brothers and sisters to learn how to read, don't you? The only books they can understand are the ones written for children, not adult books like the ones you use." Well, the ego-bolstering thoughts of being older and partially responsible for others they cared about was enough to interest them. The first book I gave them was about medieval manners. It began something like, "What would you do if you fell through the roof of a Queen's palace?" The children responded with "Excuse me please, Your Highness," holding their pants legs out to the sides. This was a marvelous parody by these "macho" children. They were able to act unselfconsciously and to begin to break down sexual stereotypes, as they indicated by

their curtsies. After practicing reading and acting out numerous episodes, they decided that they were ready to go down and perform for the kindergarten class. One returned shortly, tears rolling down his face, "Teacher, they don't listen to me." I said, "Man, now you know the problems I have. What shall I tell you? Let's think about how we can make them listen, maybe you can make them listen if . . ."

The most disruptive children in the school had become teachers. They had come to realize that they were functional members of this social grouping and individually were accepted for themselves. With some inventiveness, sensitivity and experience in interrelations with children, formerly disruptive activities had been, and again can be, translated into positive, satisfying ones.

Jeff: You've made numerous references to ecological balance. Could you clarify this?

Sava: I use the phrase ecological balance as a way of describing the enrichment and intrinsic integration of those elements that I feel all children need in order to grow, just as one of your bioshelters at New Alchemy can offer a balanced environment for plants. In an enclosed area nutrients can be supplied and utilized with sensitivity. We brought seeds, compost, water, plants, animals, and machines into our classroom. These represent elements human beings have needed always in their passage from childhood to adulthood. The sprouting plant selects what it requires for its development from its environment, balancing growth with ecological restraints. The classroom should offer optimal conditions for the children to attain within themselves, with other individuals, and with the environment. The evolution of particular modes of thinking, imagination and projection on interrelatedness can be built and unfolded in such surroundings.

Within this situation, the teacher is a gardener, a catalyst for growth, a nurturer. The sensitivity and respect the teacher should bring cannot be over emphasized. The education of teachers should span not only the learning of skills, but also an understanding of the ecology of children. This must obviously be based in part on the self-balancing in the teacher.

Jeff: How do you as a teacher bring this about?

Sava: I feel it's important to have animals, of whatever sort, in the classroom and allow children to observe them. So the adaptiveness of the animals can be seen as meaningful, I try to see that their environment is made as natural as possible for them. My class at P.S. 113 had a pair of gerbils in a "cage" that was about four by five feet and three feet deep. It contained earth and other natural materials like twigs, leaves, feathers, grass clippings and the like, collected by the children during our walks through the park. Back in the classroom, we would decide what to introduce into the gerbils' "cage." The children consulted on every aspect pertinent to the life of their "pets," giving rise to ongoing social interactions.

At one point, much to our delight, one of the gerbils appeared to have become pregnant because the other one, the male we thought, selected all the softest materials we put in the "cage," shredded them up, and, with the Mama gerbil's help, used them to line one of their burrows. And there was the nest, well-padded and protected from drafts. The next morning when we came in, we all stared incredulously at a magnificent gerbil city which they had built with the materials that we had given them. They had separated the materials and then either stored them away or used them for a variety of purposes. The gerbils had formed bridge-like structures by matting together some of the twigs and had dug an intricate maze of tunnels through the earth.

The children felt they had discovered how a gerbil might behave in natural surroundings. They began to ask questions about where gerbils live and what their life is like. We searched through numerous books. Through their absorption in the gerbils, the children used their perceptions as metaphors in telling and writing stories, in composing songs and in painting.

One day we made tapes of the children telling stories of what they'd like to be when they were older. One boy wanted to be a fireman, a girl wanted to be a mother or a nurse. Then a boy started his story, "When I grows up, I wants to be a Papa gerbil. Papa gerbil does the most beautiful things in the world. He builds tunnels, bridges and a house. He loves Mama gerbil. Whenever he passes Mama gerbil's room, she sticks out her head and he kisses her and gives her a carrot. I'm sure when the babies come, they're gonna be happy. When I grows up, I wants to be a Papa gerbil."

It was very moving. As tribal people who admire and identify with the bear or the hawk, our children had developed a larger understanding based on their experiential involvement with the gerbil.

Not long afterward, Mama gerbil gave birth to five babies. Watching over the gerbils gave the children, each in her or his own way, an admirable and desirable image of the family—a story grounded in life out of which everyone created a personal moral. Children often reject moralistic books written for them because they feel manipulated. In our case, the children were in touch with the environment, the gerbils and with each other. I didn't have to warn them about drowning the gerbils, for example. The children saw that the gerbils needed a certain amount of moisture to be comfortable. If the ground was too wet, their tunnels collapsed. If it was too dry, they crumbled. The children learned to measure more exactly and appreciated the importance of exactness in applicable instances.

The children had learned something about nature and their coexistence with it. They used materials, math, writing, painting, music, drama, and themselves

to further integrate their understanding. It was completely self-motivated. They became more aware of their own feelings and potentials, of other people, and of course of nature.

Later the principal asked me whether I would want a school like this in which the children would be there twenty-four hours a day—my answer was no. I feel that children belong to the people and to the society in which they have been brought up. They should not become withdrawn from their way of life. That is not the purpose. The purpose rather is for them to carry the excitement and the message of their education back to the people with whom they live. In this way it might not be an isolated experience, but be extended to help to create a way of life.

Reflections on the Chilean Civil War

Francisco Varela

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I can't really talk about the Civil War in Chile without being very personal. And therefore, I am quite uneasy talking here today, because I haven't spoken publicly on this matter since those events, five years ago. I guess in this group of people and given the circumstances, it is somewhat possible to do it now. But I have never done it. I would be much more comfortable talking about differential equations, or the limbic system, or something. So you will have to bear with me, because it is not the kind of thing where I can prepare something very logically structured.

So I guess I am just going to use the broad paintbrush and draw a few images for you. However, I don't think it would do us any good to have just a bunch of anecdotes or experiences without any context. So I would like to propose a context for these ideas or experiences: what these experiences have meant to me, on the basis of what we have heard at this conference yesterday and today. You see, my basic bias, my fundamental narrow-mindedness, is that I don't believe we can talk about a world view, or any

representation of what the world is, without *at the same time* observing and critically examining how these ideas come about. No content should be divorced from where this content has been produced. This goes under the name of epistemology. And so I would like to do a little epistemology.

I take epistemology quite seriously. I think it *does* matter. It is not a game or a fine pastime. Very specifically I want to go back to yesterday. And I want to make a distinction which I was very disappointed we did not make yesterday. Maybe there was no time. I want to retake the question of energy as an example of what I mean by getting us into a frame of mind about our ideas, which would include an epistemological side to it. The energy issue can serve as my example, because it was discussed yesterday and it thus becomes more tangible. And in that sense I want to make a very clear distinction between the kind of picture that Howard Odum was presenting to us and the kind of picture that Amory Lovins was presenting to us. They are fundamentally distinct: What Lovins was saying is something I can relate to and side with in many ways; Professor Odum's point of view I consider, in many respects, nonsensical. I am sorry he is not here, because I would have loved to have him hear what I have to say; in fact, one of the reasons I can say this at all is because we are in a gathering of friends, and he was present.

Now, why do I make this distinction? Well, because Odum's position about energy contains in a nutshell what I believe are the most dangerous hangovers of a kind of world view based on a purely mechanistic observer-free science and philosophy. Take, for example, his notion of the *quality* of energy in analogy with food chains: as you move "up"in a certain direction, you increase the "quality" of energy. And it's this nice exponential that he draws; that the President, with the negligible energy of pushing a button, can blow up a whole continent. In more specific terms the way he draws it is by having a system with a source and a waste, then somewhere here in the middle, in the flow, there is a nice little symbol which he calls *order*. You can call it information. This, for me, flattens out completely what I would consider what information can possibly be. Because order and information are not absolute concepts. They depend on the system that is being described, and on the describer that sees it.

If I am going to take literally what Odum is saying, then energy somehow decreases and gets to the point where it is packed with information. We ask, what kind of information is this? Is that the bureaucracy? Or is that the power of the media? Or is that the power of the workers? Whether I see the bureaucracy as having the information or the media as having the information, or the workers as having the information, these are very different points of view. I am not saying that one is particularly better than the other. Depending on where you are, order and information are going to mean different things to you.

In a compact form I could say that order is nothing more than my ability to distinguish a pattern. And randomness, by contrast, is my inability to distinguish a pattern. There is nothing "in" nature that is order, and nothing that is chaotic. There is for us the possibility of making some distinctions and drawing some inferences. And that says more about what we are doing than about what poor Mother Nature is supposed to be doing. If I show you a piece of paper and you say that it is a dirty picture, it says nothing about the paper, it says a lot about you. Similarly, if I say that there is order in society, it says nothing about where that order comes from, or how it is specified. Who is specifying that order? To put in continuity energy and information flattens out the most essential aspect of both. These notions are a reflection of a point of view, a reflection of a human stance, a cultural tradition which we all have, and in which we all move. Each of those views of order and information is going to come from such a tradition and is going to produce nothing else but another interpretation of that tradition. And it is not going to constitute a description of a state of affairs in any sense of outside, in any sense of out there.

I am claiming, in direct opposition to Odum, that information and energy have little to do with each other. Energy says as much about information as, say, block print will say about language. There is obviously the need to have some sort of structure, of a concrete physical conveyor, of a certain action that we classify as informative. It says nothing about what the informative act is all about. And to put those two levels together is to fall into the trap of the old objectivistic ideology. I believe that when it comes to issues like energy and information, particularly information, we need to bring to the foreground, and not to flatten out in neat block diagrams, these questions: Where is information generated? How is it generated? By whom is it generated? In this I am, you know, a student of Gregory Bateson, who is, as far as I know, one of the few people who really argued about this, as a lonely voice in the desert, for many years. Well, it's about time for him to be not so lonely. When somebody says things such as Odum did in this kind of a gathering, it's time for us not to just sit and relax and say, "Isn't that all very groovy?" Maybe he was using the analogy between energy and information in a metaphorical sense. It can be taken that way. But it contains a lot of technological assumptions that I don't think we can just let go unchallenged. Now, I am taking obviously a somewhat opinionated position. It is not that I am that convinced about it, but given the kind of group that this is, I thought that I might as well be somewhat less nice than I tend to be.

Energy itself is a concept that is rarely questioned at all. We forget, for example, that energy as a concept

has all the connotations of organic action at its origin in the seventeenth century. That's what energy means also, etymologically. It is usually forgotten that the discovery (or the so-called discovery) of the notion that one form of energy can be converted into another is a very interesting case of how a world view can, all of a sudden, be congealed into a solid perspective, and that people become completely oblivious to the origins. Tom Kuhn has written a marvelous paper on the idea of the interconversion of energy as a case of simultaneous discovery, how, within a period of three years, many people stumbled upon the same notion that I can take light or electricity and somehow find an interconversion factor with heat or with other forms of energy. Now, it is a historical fact that many people in Europe stumbled at the same time upon the notion that you could define this factor of interchangeability. That's what people were looking for. But that becomes an operational meaning; so many calories can be converted into so many watts or whatever, there is a very definite relationship between the two. How I interpret that is an entirely different matter. And it was in the fancy or frame of mind at the end of the nineteenth century to project the possibility of interchanging different forms of these forces that we call energy, to project that possibility of transformation, into a unified notion that energy is a *fundamental* "substance" out of which the universe is made. That is very nice metaphysics, but it is neither more nor less than that. It is not a statement about the ultimate picture of the universe. As a matter of fact, if you read, for example, Feynman's *Lectures on Physics,* published in 1965, he has no qualms in saying, in effect: "Look, I don't know what energy is. I haven't the faintest idea. All we know is that this frame of mind (of looking at different forms of measurement, these different forms of phenomena, and seeing that they can be converted into one another by some quantitative factors) is a useful one. So I go along with it. But don't ask me what energy is. I don't have the slightest idea." When good technologists forget Feynman's point and go along with the notion that the universe is fundamentally made out of energy, their quantitative point of view says that we have an energy crisis. I say we don't have an energy crisis. We have a crisis in our ideas about energy. Obviously, again, I am being one-sided about this. The case can be argued on the other side. But I won't.

Well, why does all this have anything to do with Chile?

Well, it has to do with Chile, because the Civil War gave me the experience that epistemologies are not something abstract to be given over only to historians of science; epistemology creates the kind of world that we live in and the kind of human values that we have. Not to be aware of the fact that we construct this world perspective with an epistemology is even more dangerous than a bitter argument between two philosophies. And I was trying to make a case for this in the example of energy.

You see, here the whole thing becomes personal. Chile was, for me, a process of understanding, in the midst of a traumatic social transformation. Only then were these issues made apparent to me, or at least that was my lesson from the process. And to my surprise when I left my country, I realized that whatever happened in Chile had acquired somewhat of a mythical connotation, had become somewhat of a paradigm. A lot of people were so interested in it that it was hard for me to understand why, until I saw that it is a capsule statement for many similar situations, locally, nationally, and internationally. A friend of mine recently gave me a book of poems about Chile. It's entitled *For Neruda, For Chile,* and the most interesting thing about the book wasn't what was printed, but what she wrote on the cover of the book: "There is not such a thing as a personal story." This seems to be quite true. Everybody's story becomes our story, and some of them seem to resonate more than others. So I guess this is why I thought it might not be idle to convey to you some of the experiences in Chile.

Chile is a strange country. I cannot separate it from its landscape. You go to Chile to find yourself in the middle of a mountain and at the edge of the sea. You cannot get away from that haunting sensation of being sort of dangling almost out of nowhere, with only about two hundred miles to move across. The fact that it is such a long country, going almost all the way from the equator to the antarctic, gives one the feeling of being in a long corridor. That gives the Chileans a character somewhat different from that of other South American peoples in the Inca-based countries (Peru, Bolivia, Ecuador) and very different from heavily European-influenced Argentinians. Argentina is more like the United States than any other South American country. Chileans, by contrast, are very withdrawn—a somewhat melancholic people used to the rain and cold. One of the most impressive things about the country is the Chileans' love for poetry. For some reason, everybody in Chile writes—or at least loves—poetry, and poets are the best national heroes. I have never been to a country where ten or twelve major poets are sold together with the porno magazines and Donald Duck. Well, that is partly what the country is.

In 1970 came the well-known election of Allende, the first Marxist politician ever elected in a free election. The thing to realize here is that the 1970 election cannot be taken in isolation, cannot be taken out of context, but must be seen in a forty year or forty-five year long and slow-moving growth of a broadly based worker movement. When 1970 came, Chile probably had, percent-wise, the largest organized labor force in the whole world. Literally half of the workers were part of active political

movements and had been involved for years in the labor movement and in labor participation, so that the level of political sophistication is something unusual in South America. Allende wasn't an accident, he wasn't a weird thing, but the conclusion of a long process and a long tradition.

Now, I suppose it is very hard to convey the sense of what the election generated for all of us, the sense that everything was possible. The 4th of September, the night of the election, I remember everybody poured out onto the street and started jumping like kids. For about two hours you could see 500,000 people jumping up and down like kids. We had a sense of a tremendous opening, a tremendous hope. I won't make a political analysis of the three years of Allende, because I couldn't do it. I'm not really a political scientist. Others probably would know much more about it than I would. But what I do want to paint for you are some of the events during those three years, the general way things began to go, and what forces were brought to bear upon it, internal and external. From this sense of opening and exploration, what began to happen was the development of polarity: in other words, polarity in terms of either supporting, being on the side of or against the movement, not the government, particularly. That's another misconception that I always find. The government wasn't so important as the parties behind the government. The coalition of parties was an indication of the kind of political mentality prevailing at that time. Allende wasn't caudillo. He wasn't a leader per se. He was the head of a vast force, a political party. And that was what really carried punch. So polarity revolved around siding for or against the popular fron, which by 1973 was about 43 percent of the vote. It quite literally split the country in two.

I cannot be emphatic enough in saying that this is literally splitting it in two. You could go to the newsstands in the morning and one newspaper would say "It's raining," the other would say "It's not raining." "A is a son of a bitch"; "A is the king of the universe." It was literally like that. And you know, three years before, these two were reasonable newspapers, who agreed that a table is a table and blue is blue. But by 1973 this was not possible any more. They couldn't literally agree on anything, the time of the day or the color of the sky. It was absolutely and right down the middle a complete split. And that sense of polarity created a sense of "we're right," or "they are right." The polarity created a continual exaggeration of the sense of boundary and territoriality: "This is ours; get out of here."

For me, this was the time at which things began to get very, very confusing. I started out being very supportive of the whole thing. I worked pretty hard, like many other people, doing what I felt was possible. I was doing nothing fancy. I wasn't ever a high official in the government; I was just doing my sort of grassroots work. But by the second year the polarity began to develop, and I began to have my serious suspicions, to doubt whether this was making sense or not. I couldn't believe that the other guys, on the other side of the fence, were so bad, stupid, wrong, immoral, ugly, and so on and so forth, as I was supposed to believe. There was something that wasn't jibing any more. And I was very, very confused by the whole thing and caught in a dilemma of loyalty to what I felt was essentially my people, my friends who were into this together. I mean, I wasn't apt to jump out of the boat, but I was beginning to lose my whole conviction, my whole commitment to the idea of defending this thing.

That was the state of affairs in which I was by the end of 1973. I didn't have any sense of understanding at all. I was in the uttermost confusion about the whole thing. And the only thing that was keeping me going was simply a sense of solidarity. I remember walking down the streets the first days of September, having a burden on my shoulders, I guess like everybody else. I had a sense of impending doom and no understanding any more of what this was all about. Where did it all begin? I don't know how to say it vividly enough; it was absolutely and completely chaotic. In the literal sense of the word chaotic. There was no possibility of distinguishing any order or any rule any more.

So it is Tuesday, September 11th, 1973. It is not raining, but the radio says it is raining. I am waking up in the morning at around 6:30, taking my little daughter to her nursery school and the radio keeps saying "it is raining," but it is not raining. I thought: These guys are crazy. And as I am walking out of the house to take my car, the young neighbor runs across the street and says; "Don't you know?" "No, I don't know." And only then did I learn that half of the radio stations are taken over by the army. And they are broadcasting their decision to overthrow the government. Then I remember--stupid of me--that the code, "It's raining" means that a coup has begun. I had been told that about a month before and had forgotten. So I take my daughter back to the house and take the rest of the family to a next-door neighbor, who was a very quiet person. And I go to join, as it was agreed, the people that I was working with at the university to see, you know, whatever is to be done. Supposedly it is civil war, so everybody is assigned certain tasks. So it is ten o'clock in the morning, and three-quarters of the radio stations are already taken by the army. And we're all sitting; we are supposed to be waiting for the instructions to do whatever. But no instructions come. We all sit there with the same sense of impending doom, not believing that this is happening. The war is still an abstract thought, still something that is not really happening. We have never had a war in Chile before. I have never seen a war. Nobody has ever seen

the army on the streets before. Nobody has ever seen the police be anything except very nice people. So there is no frame of reference. This is abstract.

So it's ten-thirty in the morning, and most of the radio stations, except one, are already taken by the army. And I begin to see tanks rolling down the streets, and I begin to see wagons loaded with soldiers driving down the street, and I begin to see the airplanes, war planes, flying over the city. And I begin to recognize that funny sound of submachine guns, distant from where I am. It is eleven o'clock in the morning, and we know that every faction of the army has turned against the government, or those that haven't have been isolated. We know that the President has decided not to surrender, but to stay in the presidential palace, and they give him an ultimatum before bombing. So we know that there is no way back. Bullets are already screaming over your head, so you know that the war is not abstract. It has a very concrete sound to it, that funny whistle of the bullet, that you can't locate except after it is gone. And still we don't have instructions. So the local leader decides that we are to disperse to different places and hide out until we receive instructions. So I go with four other friends to a place in which we are going to hide out and wait until the moment to do something comes. We must walk, oh, twenty blocks to where we ought to go. And as I walk out, the reality of war becomes already vivid. I see a tank bulldozing over a wall in a factory that is occupied by some twenty-odd people with some light guns. The tank blasts through it and turns around the thing after it is blasted, so I see some twenty or twenty-five people, the first twenty-five or so people, in which polarity is not any more an abstract idea but twenty-five people whom I can hear. I am scared. I have never been in a fight before. I hardly know how to use a gun. Down the street, a couple of blocks away from where I am, a man runs down the street to the intersection, and as he reaches the corner, I see coming from the other end a soldier who riddles him with bullets. So we keep walking and we finally get to the place where we are supposed to go.

Now, at this point, one o'clock, the presidential palace has been bombed. We can still see the Hawker-Hunter plane hovering around not only the palace but other important places in the city. And we know that the rug has been pulled from under us, that there is no sense in which we know what is happening any more. There are no instructions. There is no government. The military, whom we had seen before as somewhat respectable people, now we can see that they are not. I remember very well that the soldier, whom I saw machine-gunning the other fellow who was running down the street, was probably a nineteen-year-old boy from somewhere in the south. A typical face of the people of the south. Probably, if you had met him two months before in a bar, you would have had a swell conversation—a sweet boy. He couldn't be more than nineteen, yet I could see in his face what I had never seen, a strange combination of fear and power. So those people I don't recognize any more; I don't know their faces any more. We are all stranded in this place, and we know that there is simply no hope. If they decide to come after us with automatic M-2 rifles, the best you can hope for is not to be treated too roughly. So, it is three o'clock in the afternoon, and the whole city has been vacated. There is nobody on the streets, because curfew has been imposed. The only thing you can hear is the constant rattle of the machine guns, a sound that you hear for the next two weeks, which by now is a familiar sound to me. And you start waiting. And there is no radio, no communications. So I waited Tuesday afternoon, Wednesday morning, Wednesday evening, Thursday morning, Thursday afternoon. Curfew is lifted. So we can go out. But those days we wait with that strange sense that you don't know when your last moment will be. Anytime they might come in, and that's going to be it. So you have that funny relationship with people, knowing that you might be doing the last thing you will ever do, you might be saying the last thing you will ever say. So what do you say? Little silly things. You draw little figures on the foggy windows.

For me, at that time, the ground had been pulled from under me. Nothing else was left to hold on to. At the same time a very funny and contrary process happened; as things got more and more chaotic, the evidence of what a war is, there was a strange form of clarity coming more and more, a strange form of understanding, which I can't really express. I suppose it is somewhat like a semi-dream state. At the same time it was very real, because in this room with these people I could literally see how this whole thing wasn't me here and they there. But I could literally see how the army, and that nineteen-year-old boy shooting somebody down, wasn't distinct really from me. I could somehow contemplate that murder with a sense of brotherhood at the same time. Polarity wasn't any more this and that side, but something that we had collectively constructed. Literally a collective action that we had all done. As this became more and more clear to me, it dawned on me that whatever my stances had been, my opinions had been, or whatever somebody else's opinions had been (and the workers' opinions and what not), were fragments that constituted this whole, this complete mandala of sorts. That all of a sudden it revealed a craziness. Total craziness. I mean, this is somewhat as when literally someone is really crazy. You see the mind completely out, the brain turned upside down or inside out. Well, this was like that, except this was a whole country, or a whole city of three million people. That's what my actual experience was; three million people being turned upside down the same way. And you see the

craziness, the way in which there was a collective pattern in which I was responsible, everybody was, and in which my views couldn't any more signify anything except that piece of a larger puzzle for which I really didn't have any answer.

So, it might sound strange, but Wednesday night I gave in to it, and I sat down and wrote some twenty or so pages that I entitled "The Logic of Paradise," because it seemed to me for the first time that this had a logic to it. The whole thing had an intrinsic logic that was essentially good, in that it gave me a handle on what paradise is, for the first time. I know that might sound strange, but that is what it felt like—that being rooted in the complete chaos and mass killing, out of that was emerging a completely inverse understanding. And I was too scared or something to resist it. So somehow it just got transformed into those pages.

Now, that experience is what was given to me, is what I have had to deal with ever since. Because it revealed to me the connection between the world view, political action and personal transformation. It revealed to me, in a way that I knew but really didn't know, that I somehow vaguely understood but hadn't experienced, that unless I was able to cut through my sense of identity and attachment and identification with what I believe are my ideas, my things, my territory, my limits, I had no hope of understanding what the hell was going on. And it literally turned my life inside out. What that experience told me was: "Unless you build on the foundation of working with that sense of spirituality, (what later on I began to understand was what religions are talking about) unless you build on that base there is simply no hope of understanding." I have found, for myself, expression of that understanding in Buddhist practice. I cannot separate that practice, that sense of working with the contemplation of how my mind and my actions generate and operate. I cannot separate that from political action and from what my understanding of the world is. I suppose this is why I become so passionate about issues on epistemology. Because epistemology does matter. As far as I am concerned, that civil war was caused by a wrong epistemology. It cost my friends their lives, their torture, and the same for 80,000 or so people unknown to me.

So it is not an abstract proposition for me when I say that we must incorporate in the enactment, in the projecting out of our world views, *at the same time* the sense in which that projection is only one perspective, that it is a relative frame, that it must contain a way to undo itself. And unless we find a way of creating expressions of that nature, we are going to be constantly going around the same circle. Whether that can be done or not I do not know. But if it can be done at all, it can be certainly done with a group of people like this. My deep conviction is that we must try to see to what extent our political views and our projections on the world can express this form of relativity, the fact that every position we take will also contain the opposite one. That ultimately I cannot follow a form of political action that is based on truth any more. I cannot say that my political stance is true as opposed to yours, which is false. But every political stance contains the elements on which the truth of the other is based, and that all we are doing is a little dance. Sure, I have to take this side, and that is cool, but how do I really embody in that action that I acknowledge the importance of the other side and the essential brotherhood between those two positions? How can I go to Pinochet and say, "Hello, my brother?" I don't know. I don't think that I am that enlightened at all. I wouldn't be able to do that, but in some sense I realize that is a great limitation. That should be in some sense possible.

I am going to end here by summarizing this theme that is one of my major concerns: I don't believe any more in the notion of a cultural revolution in the sense that one form of politics and knowledge and religion is superseded by a new one. If I am interested in doing anything at this point, it is in creating a form of culture, knowledge, religion, or politics that does not view itself as replacing another, in any sense, but one that can contain in itself a way of undoing itself. If we are not here to do that, I quite frankly would rather go skiing.

Index

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